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AMERICAN WATER WORKS ASSOCIATION

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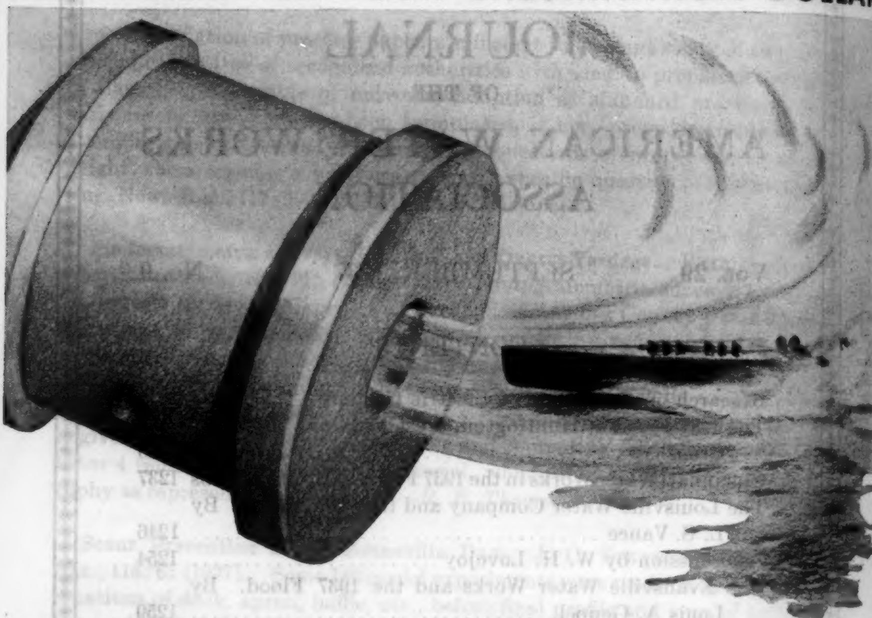

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AMERICAN WATER WORKS ASSOCIATION

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RESEARCH ON GROUNDING OF ELECTRIC CURRENT*

INTRODUCTION

For a number of years, the American Water Works Association has had committees organized for the purpose of studying the effect of electric current upon water works piping systems. In recent years, the activity has centered about the effect of grounding house wiring on service pipes. The Association is represented on A. S. A. Committee C1 (National Electrical Code). It has recently appointed a representative to the Bureau of Standards committee on National Electrical Safety Code.

In 1936, the Association joined with the Edison Electric Institute in the formation of "The American Research Committee on Grounding." The background of this has been recorded by the Secretary of the Committee in the following statement:

"The National Electrical Code as early as 1901 permitted the grounding of secondary circuits. In 1903 the Code recommended that such circuits be grounded. It was not until 1913, however, that the rule was made mandatory. At the present time such grounding is specified also in the National Electrical Safety Code and in practically all city or state electrical codes where such exist.

"Ordinarily, the most effective grounding electrode available on a consumer's premises is a continuous metallic underground water-piping system. The reason why such a water-piping system makes

* An Editorial Statement recording Water Works Practice Committee activities through its sub-committee on "Electrolysis and Electrical Interference."

the best ground is not because the pipes have water in them but is because such a piping system has a large contact surface with the conducting material of the earth. Furthermore, water pipes appear at numerous points throughout the house and are interconnected or in contact with steam pipes, gas pipes, etc., so that collectively these pipes offer numerous chances for people to make contact with them. . . .

"At first, many water purveyors objected to the use of water pipes for the grounding of alternating secondary distribution circuits. They had experienced considerable corrosion trouble from direct current on their pipes and therefore hesitated to permit connections which might introduce alternating currents on their piping systems.

"The question was extensively discussed for several years. In these discussions it was brought out that (1) protective grounding to water piping systems, where such were available, constituted the only effective practical safeguard to life and property and that (2) such connections would carry appreciable current only during short and comparatively infrequent periods when abnormal disturbances of the electric system caused these ground connections to fulfill their protective purposes. On such a basis, the American Water Works Association in 1920 adopted a resolution approving the grounding of secondaries of lighting transformers on water pipes for protective purposes.

"As the practice of grounding secondary circuits became extensively introduced, water purveyors from time to time received complaints that their ccustomers or employees received shocks from water pipes and that electric sparks occurred between disconnected ends of water pipes when meters were removed or reset. In certain situations the use of multiple grounds on the same secondary circuit short-circuited insulating joints in water pipes, thereby nullifying the value of such joints as protection against corrosion. . . .

"In recent years there have also been complaints of objectionable odor, taste, color, or sediment in water, which could not be accounted for or remedied by accepted water works methods. This type of trouble has apparently been confined to one or a few houses in a given locality. In a number of such situations the only apparent difference between locations having trouble and locations having no trouble was that there were currents on the service pipes in the one location and not in the other. . . .

"In May, 1935, the matter was brought to a head because the American Water Works Association rescinded its previous official

sanction of grounding electric light and power circuits on water pipes. Shortly thereafter, the Association entered formal protest with the American Standards Association against adoption of the 1935 edition of the National Electrical Code as an American Standard. After a consultative review of this problem, this formal protest was withdrawn, on the understanding that a joint committee would be formed to make a cooperative study of this problem. . . ."

The organizations participating in the work of this Committee are:

American Gas Association
American Institute of Electrical Engineers
American Society of Sanitary Engineering
American Standards Association, Telephone Group
American Transit Association
American Water Works Association
Copper and Brass Research Association
Edison Electric Institute
International Association of Electrical Inspectors
National Association of Master Plumbers
National Board of Fire Underwriters
National Bureau of Standards
National Fire Protection Association
New England Water Works Association

The objectives of the research are "to investigate and report upon, as conclusively as may be: (a) electrical grounding connections, made to water, gas, or drainage pipes, with respect to the effects of any kinds of electrical current thereby caused to flow, upon (1) the pipes, (2) the contents of the pipes, and (3) fire and personal hazards; (b) conditions in the electrical circuits involved which produce current flow over pipes; (c) measurement of stray currents; (d) efficiency of electrical grounding."

The American Water Works Association is represented on the joint committee by M. W. Cowles, E. E. Minor and C. F. Meyerherm. Mr. Meyerherm is secretary of the joint committee and H. S. Warren, of the Bell Telephone Laboratories, is chairman. Two statements to the Association made by Mr. Meyerherm on behalf of the committee follow:

STATEMENT OF JANUARY 13, 1937

The work of this association's committee has been almost entirely connected with the activities of the American Research Committee on Grounding whose technical sub-committee has undertaken a number

of field investigations. These field investigations followed the Committee's letter of August 5th, 1936 addressed to some fifteen water works operators located within 100 miles of New York and requesting them to bring to the Committee's attention instances of corrosion, electric shock, or water impairment which they believed or suspected might be due to electrical grounding. So far the Committee has investigated four of these cases. In each case the investigation disclosed so many factors whose influence might affect the particular problem that the Committee's work has become exceedingly complex and no definite conclusion can be drawn as yet.

The work is proceeding however, and as the Technical Subcommittee becomes more familiar with the problem and as test methods and equipment become standardized, more progress will be made.

For the present, it can be said that a very extensive and comprehensive test procedure is contemplated, and that the Committee is sparing neither time nor effort in its search for complete and conclusive data on the grounding problem. Certain phases of this problem will unquestionably require the highest type of technical research work, and probably some pioneer work in a number of more or less unexplored fields.

The members of the Technical Subcommittee are working on a most cooperative and friendly basis which speaks well for the ultimate attainment of an engineering solution to this troublesome problem. Before this solution can be attained, however, the water works industry must do its part not only in reporting cases of trouble, but also in investigating and developing all of the facts relating to the water works side of the grounding problem. This will naturally involve expense but if the water works industry as a whole expects a satisfactory solution of the troublesome grounding problem they cannot afford to let matters slide and they must be prepared to match the effort of the other interests on this committee and present the water works case on the strongest possible engineering basis.

STATEMENT OF JULY 2, 1937

The American Research Committee on Grounding met on June 16, 1937, to review the progress made by its Technical Subcommittee since the previous meeting.

The Technical Subcommittee reported that, to initiate its test program, a number of water purveyors operating within a radius of

100 miles of New York had been invited to report cases of water or piping trouble believed or suspected to be due to electrical grounding to the subcommittee. The 100-mile limitation was set in order to minimize time and expense in traveling. Letters were sent to 17 water purveyors but no cases have been received in answer to these letters. Twenty-two cases, however, have been reported to individual members of the working subcommittee, and sixteen of them have been investigated by the subcommittee. A number of these were in the territories of water purveyors to whom the invitations were sent. The complaints as reported may be listed as follows:

	Cases
Sediment in water	2
Blue or green stain	7
Rusty water	2
Failure of boiler tubes	2
Service or house pipe corrosion	4
Electric spark	1
Taste and odor	1
Miscellaneous	3
Total Reported	22

No one of the investigations is considered as finally completed.

While the field investigation varied with each situation, in general the procedure was as follows:

1. The local water purveyor, the local electric company, and sometimes the local gas company participated in the investigation.
2. The history of the complaint was reviewed and recorded.
3. A record was obtained of the water and gas piping systems involved, including main, service, and house piping. A record was also obtained of the type and condition of the electric services and house wiring involved.
4. Measurements were made and recorded of currents both alternating and direct, at various locations on the premises, with an artificial load where necessary to make adequate measurements.
5. Samples of the water were taken for analysis, where pertinent.
6. Where sediment was found to be involved, a milk filter with cotton discs was used. A definite quantity of water was passed through the filter. The appearance of the

disc gave a simple method of determining visually the amount of sediment.

7. Samples of pipe or fittings were obtained, where pertinent. The development of a technique for these investigations has taken some time, particularly for the earlier cases. In general, one or two visits have been made to each location.

In most of the sixteen cases the cause of the complaint could not be attributed to any single factor. In some of the cases where alternating current was found, removal of the alternating current has not to date substantially altered the manifestation causing the complaint. However, this does not definitely show that alternating current does or does not contribute to the effects but rather that other factors, such as high water temperature of water heaters, galvanic couples due to dissimilar metals in use in plumbing work, and differential aeration, may have been more important in these particular cases.

Where more than one factor contributes to the cause of complaint, the exact part each factor plays in the final result cannot readily be determined in the field. Likewise, the removal of one cause, such as galvanic couples, by the use of insulating bushings, removes other factors as well, such as the flow of alternating current on the section of pipe.

It appears that a laboratory study may lead to the determination of what part such factors may play in causing the complaint, and may permit the field investigators to determine more accurately the exact cause of the complaint.

The committee approved the recommendation of the subcommittee that:

1. A study be made to determine whether or not laboratory investigations would facilitate the investigation and, if so, to prepare for consideration a program of such laboratory tests and means for carrying out these tests.
2. The field investigations be continued. The analysis of sufficient data is necessary to develop methods of testing and good practice in controlling causes of complaint.

In presenting its report, the technical subcommittee pointed out that in none of the cases so far studied are the results to be regarded as final.

COMMENT

The secretaries of all A. W. W. A. sections have been furnished copies of these statements with the suggestion that discussions of the problem be scheduled for section meetings. Experiences of meter setters with undue load on water pipes are obvious evidences of the situation. The more subtle effects of grounding on quality of water in a residence are not so easily appraised. It does appear, however, that investigators of complaints and purification plant chemists could properly satisfy themselves, when an otherwise unaccounted for consumer complaint of taste and odor occurs, that electric current conditions are not contributing to the adverse condition.

THE 1937 FLOOD AT HUNTINGTON, WEST VIRGINIA*

By J. C. Crenshaw

(*American Water Works and Electric Co.*)

(*New York, N. Y.*)

It rarely happens that a water company experiences a general interruption in service, and when such instances do occur the causes are generally traceable to elements beyond the control of the officers and operators. An interruption in service, however, from any cause, is such a serious matter to a water works man that he cannot help but study such experiences to see if there is any reasonable precaution that can be taken to prevent a recurrence.

When in two successive years, 1936 and 1937, the South Pittsburgh and Huntington plants of the American Water Works and Electric Company were forced to shut down vital pumping stations because of floods, the first reaction was naturally to wonder whether proper thought had been given to arrangements for protection against flood waters.

However, a study of the records reveals the purely coincidental character of those two floods in successive years. A review of the long-time record of Pittsburgh covering a period of nearly 200 years, indicates that the Company, on the basis of its experience in 1936, would have been able to continue operations in any flood during that period and probably in any previous period. The history of the situation at Huntington reveals that the plant has withstood all previous floods without interruption of service, the highest previous flood level occurring in 1913, at which time the crest was only a few feet below that in 1937.

The experience at Huntington in 1937 indicates that beyond certain limits it would be clearly uneconomical to protect at necessarily great expense a pumping and filtration plant against inundation during rare, long interval floods. The force of the flood waters washed away a great many houses, leaving the broken services running open. In numerous cases the piping in abandoned houses

*Presented at the Buffalo convention, June 9, 1937.

froze and burst, and in the following temperature rise the waste from this source was added to the drain on the system. A total of several hundred service lines was affected, and, had the pumping and filter plants been protected by a levee, it is extremely doubtful if service could have been maintained.

The high service pumping station and filter plant at Huntington are located on the river at an elevation of 24.5 feet above flood stage and the low service station is located approximately 32.5 feet above flood stage. Both the high service pump station and filter plant were flooded. The low service plant was not affected by the high water.

OPERATION DURING FLOOD PERIOD

Where a water works plant is not protected by a levee it is possible, while the waters are rising, to barricade doors and openings to withstand several feet of water above operating floors. The nature of the soil, depth of building foundations, construction of building walls, etc., to a large extent determine the amount of water which will actually enter the plant after the flood waters have risen above the operating floors, and examination should be made to eliminate pervious materials and openings normally used in operation which can allow very high waters to enter. It is needless to say that all sewers and drains must be closed in order to prevent water from entering the station from this source.

For this period it is necessary to provide sufficient auxilliary pumping equipment to discharge the leakage from within the plant. The portable type gasoline engine driven centrifugal ditch pumps are satisfactory for this work. It is well to elevate this equipment as high as possible above the floor in order that it will not be submerged should it be necessary to abandon the station. In some instances, where the high service and low service plants are under the same roof, it is possible to divert a part of the leakage into the low service pits and allow the low service pumps to take suction directly from the pit. This is particularly true of steam reciprocating equipment both horizontal and vertical. This method of operation, however, is not satisfactory with motor driven centrifugal low service equipment due to electrical hazards and the difficulty of arranging for taking suction from the pit with a centrifugal pump.

The limit to which a water works plant, including both the pump station and filter buildings, can be barricaded and still operate safely, depends largely upon local conditions and the design of the buildings.

In addition to the danger of collapsing the walls of the buildings the problem of preventing outside water from entering clearwater basins is a difficult one. The ability to prevent water from entering the clearwater basins depends, of course, upon the construction of the filter plant and its elevation with respect to flood water. Ordinarily, the top of a clearwater basin is not designed to be watertight, but it should be so constructed where there is the remotest possibility of flood waters reaching it. Underground storage tanks as well as those above ground should be prevented from floating by filling with water; if this is impossible, they should be weighted. Concrete floors of pits should also be protected by "weighting" down if they are not of such construction as to withstand the upthrust of the water. Pig lead, sand bags or other heavy material is satisfactory for "weighting."

As can be imagined, the operation of a water works plant becomes increasingly difficult as the flood waters rise, due to the increased leakage and the inaccessibility of plant buildings should they be separated. As a general rule, most water works plants, if the pumps be steam operated, carry on hand a sufficient amount of coal to last for several weeks. This is also true of purification material such as lime, alum and chlorine, which eliminates a serious transportation problem.

Emergencies of this kind emphasize the desirability of maintaining a reasonable stock of operating materials and supplies on hand to meet any unforeseen operating conditions.

As has been seen in recent floods, it is difficult to determine the flood crest with any great degree of accuracy. In holding out against slowly rising waters, it is possible for the plant operators in their efforts to keep the station in operation, to neglect certain measures with regard to abandoning a plant. When flood waters have reached such a stage as to make it necessary to barricade the plant, it is desirable to pump at such a rate as to keep the storage reservoirs or tanks filled at all times, if such reservoir capacity is available. Ordinarily, where reservoirs of any substantial capacity are a part of the distribution system, they are allowed to float on the system, receding during the day and filling at off peak periods. At the first indication that a station may have to be taken out of service, the storage reservoir or tank should be filled to capacity and, if practicable, isolated from the distribution system in order to conserve this supply of water.

ABANDONING OPERATIONS

When it is decided to abandon a station, if it be steam operated, the pumps should be shut down and valves left in such a way as to cause the least possible delay in putting the pumps back into operation.

Even in steam plants there is more or less electrical equipment. Small motors and switchboard equipment should be removed and placed above the high water. Cranes and hoists should be available to lift large motors and generators above the high water and allow them to remain suspended. Should there be turbine driven centrifugal equipment, the reduction gears should be disassembled and removed to a dry place. This will not only eliminate the necessity of cleaning the gears before the unit is placed back in service, but will insure against the gears becoming pitted. There is, of course, a limit to the amount of equipment that can be removed and placed above high water, and this is dependent upon the speed of the rise of water and the definiteness of the height of the crest.

EMERGENCY SERVICES

After pumping operations have been discontinued, it is necessary to furnish potable water to consumers for drinking and cooking purposes. It was mentioned earlier that it is wise precaution, if a system has available storage capacity, to isolate the reservoir or tank from the distribution system at the first indication that pumping operations may be endangered. This phase of operation will depend upon the locality served. In low flat sections many houses may float off their foundations breaking the water service connections. In such cases, if the reservoir or tank has not been shut off from the distribution system it will soon become depleted.

After the inundated section of the distribution system has been valved off it may be possible to serve partially certain territories not affected by the flood, directly from the reservoir. The amount of available water in storage and the estimated period of shut-down will be a controlling factor in the distribution of this reserve supply. If only a limited amount of water is available it may be undesirable to attempt to feed any water through the pipe system, due to the amount wasted in filling it once or twice a day. In the cases of both South Pittsburgh and Huntington, a fleet of trucks was engaged and potable water transported in large sterilized containers to consumers in those sections without water. Each container was equipped

with a lid and the persons actually engaged in distributing the water were cautioned to handle it with care to avoid contaminating.

It is advisable to lay out the territory to be supplied in such a way that certain trucks will cover certain areas at regular intervals, say twice a day. This will reduce to a minimum the traveling time of the trucks and will more evenly cover the territory. Streets should be taken in order and the people notified by the ringing of a bell or other means that water is available. Since it is impossible to haul water other than for drinking and culinary purposes, the amount allowed should be determined by the size of the family.

At the two plants referred to, sufficient water for drinking and culinary purposes was furnished consumers either by means of hauling or direct from elevated storage. Judging from the many favorable letters received from customers, civic bodies and municipalities, as well as several complimentary newspaper editorials, it was apparent that the public fully appreciated the efforts put forth by the Company and realized that the temporary interruption in regular service was beyond human control.

If there is no storage in connection with the distribution system from which to take the supply for hauling or if the storage supply has been depleted, it will then be necessary to resort to neighborhood wells or springs. In order to make sure that this source of water is safe for consumption, it is advisable to treat the water with a solution of hypo-chlorite of lime in the correct amount. As an additional precaution, all persons receiving water should be cautioned to boil it before using.

RE-STARTING THE PLANT

After the flood crest has past and the water has receded to a point below the top of the barricades, the work of "unwatering" and cleaning the plant can be started. If the lighting system has been put out of service by the water it will be necessary to provide lights for night work. Portable carbide lights have been found satisfactory. At Huntington and at Pittsburgh the year before fires were started under the boilers while there was still a foot or more of water on the boiler room floor.

The length of time required to put the pumps in operation will depend upon the type of equipment installed. In this respect steam reciprocating pumps and their auxiliary equipment offer the simplest problem, since there is very little cleaning necessary prior to placing these pumps in operation. If need be they can be operated entirely submerged.

The reverse is true of steam turbine driven centrifugal equipment. Before this equipment can be put in service it is necessary to remove and thoroughly clean all lubricating oil lines, bearings, bearing housings, oil coolers and reduction gears if same have been submerged. The cleaning operation can probably best be done with kerosene rag swabs and live steam. From experience it has been considered unnecessary to remove turbine casings for cleaning internally.

The problem of restoring service in electrically operated plants subject to floods, is a serious one, provided measures have not been taken beforehand to protect at least the major equipment. By major equipment is meant motors driving pumps, motor-generator sets and transformers. If these have been kept dry it is possible to make temporary connections and operate the equipment. This was done at Huntington and a 500 horse power synchronous motor driving a 7 m.g.d. pump was put in service. It was necessary, however, to start the motor directly across the line, permission having been granted by the Power Company. With partial or normal pumping operations restored, water under pressure will be available for cleaning purposes.

The amount of debris and mud deposit in a station will depend upon the location of the plant and the locality with respect to the flood. Fortunately, at Huntington practically no deposit was left in the station and very little cleaning was necessary.

THE FILTERS

The operation of the filter plant under flood conditions presents very troublesome problems. It is not unusual for the pumpage to increase as much as 100 percent over normal operation due to broken service connections, leaks in mains, and after the waters have receded, an excessive use of water for cleaning. Naturally with the filtration rate considerably increased and a more turbid water to handle the chemical treatment of the water must be watched closely.

In addition to the chemical problems involved there may arise problems of a mechanical nature. Pumping operations having been interrupted, pressure in the transmission system will be very low if not zero. Where the operation of hydraulic valves, chlorinator jets, coagulant feed jets and the washing of filters depend upon pressure from the transmission system, it is important that the transmission lines have valves so arranged that they may be partially closed in order to build up sufficient pressure for these uses. The installation of wash water pumps is, of course, more or less a common practice and

it may even be considered advisable to install a small pump for the other uses mentioned. Large valves on the outside of the pump station should be carefully located in order to facilitate their operation even under water.

THE DISTRIBUTION SYSTEM

Coincidental with restoring service in a pumping plant is the necessity for restoration of service in the distribution system. As has been brought out previously, if certain sections of the distribution system have been damaged by the flood, if feasible, these sections should be valved off in order that service may be restored in the sections less affected by the flood.

During the time operations are suspended and until they are again restored, it is possible for outside water to have entered the distribution system through breaks. When service is resumed this untreated and possibly polluted water will be forced to other parts of the distribution system. Under such circumstances, it is therefore necessary that consumers be notified to boil the water at least twenty minutes before using it for drinking or cooking purposes even though the water being pumped is heavily chlorinated.

Due to the large amounts of water being used for household cleaning purposes, it may require several days for the pressure in the distribution system to reach normal. Until a more normal operation has been restored, cooperation should be asked of the city street department and those having private fire protection in limiting the use of fire hose for cleaning streets and buildings.

In outlying districts or on dead end lines where the draft is small, flushing should be practiced in order to draw chlorinated water into the mains. Frequent tests should be made throughout the system to make sure that there is residual chlorine in the water.

Before restoring service to those sections damaged by the flood it will first be necessary to make a survey and turn off service connections to houses that have floated away. If cold weather prevails it is advisable to also shut off service connections to houses that have been abandoned to prevent the loss of water through frozen and burst plumbing.

And finally, when service has been restored to all sections of the distribution system, a thorough and continuing check should be made in an effort to find and correct all leaks for it must be expected that it will be some time before pumpage will return to normal level.

CINCINNATI WATER WORKS IN THE 1937 FLOOD*

By A. S. Hibbs

(*Superintendent, Water Works Department, Cincinnati, O.*)

During the latter part of January and the first part of February, 1937, Cincinnati and nearly all cities in the Ohio Valley from Portsmouth to Cairo, were hit by the highest and most disastrous flood on record. In Cincinnati, the flood reached the record stage of 80 feet, nine feet higher than the flood of 1884 and ten and one-tenth feet higher than the more recent flood of 1913. When one considers that 52 feet is flood stage, the magnitude of this flood is more fully realized.

Beginning early in January there was, throughout the entire Ohio Valley, an abnormal and continuous rainfall which set the stage for this greatest flood in the history of Cincinnati. The average normal rainfall for Cincinnati for the month of January is 3.48 inches. The January rainfall for this year was 13.48 inches, or approximately four times normal. On January 16th, the river at Cincinnati had reached a stage of 51.7 feet and people were beginning to give thought to the usual preparations for a flood. The water, however, began to recede before the 52 foot stage was reached. It dropped back to 49.9 feet and those to whom the annual river rise is an expected inconvenience, felt a sense of security in the belief that this particular threat had been averted. Then the unusual happened. Beginning on January 17th, a continuous downpour throughout the southern part of Ohio and the northern part of Kentucky and other territory tributary to the Ohio River brought about a condition which caused a rise in the river of 6.2 feet in one day. On Friday, January 22nd, the river had reached a stage of 71.2 feet and the old record of 1884 was past history.

Late in the afternoon of Friday it turned cold and within a few hours freezing weather accompanied by a heavy driving snow spread over the entire area of Southern Ohio and Northern Kentucky.

By Saturday afternoon the river was practically stationary at

*Presented at the Buffalo convention, June 9, 1937.

approximately 73 feet, and every one felt that the worst had passed even though the predicted crest of 73.5 feet might not be reached until Sunday or Monday.

THE PUMPING STATION

The Main Pumping Station of the water works, through which all of Cincinnati's water passes, is literally the "heart" of the entire water works system. Except for storage in reservoirs floating on the distribution system, the city of Cincinnati would be without water if this station should be forced out of service. Realizing the necessity of protecting this vital spot, all door ways and openings of the station were sand-bagged and emergency pumps installed to keep the level of the seepage water in the pump pit as low as possible.

Levels taken around the station indicated that it could be protected to a flood stage of about 74 feet and on Saturday morning, all consumers were advised to draw an emergency supply of water, if possible, as it was felt that water drawn for this purpose while we were still pumping might be very valuable after a shut down, as it would add to the general storage on the system. This warning was pretty generally heeded and undoubtedly was instrumental in keeping the water shortage, which soon occurred, from being more serious than it was.

With January 24th, however, came more adverse conditions. On this day, which is known as "Black Sunday," a rain set in which soon became a down pour, continuing throughout that day.

The water flowed down from the saturated and snow covered hilltops into the lowlands carrying with it, the melting snow. Now another jump in the river stage of 5 feet occurred and a new and unprecedented height had been reached.

During the morning gasoline tanks at a large oil company's plant were forced from their foundations by the rising waters, pouring their contents upon the surface of the flood. About 10:30 A.M., a shorted electric wire furnished the necessary spark to start a fire which took until Sunday evening to control and caused a property loss of over $1,500,000.

The flood waters made it practically impossible to fight the fire. One Fire Lieutenant said that it was the first fire he had ever seen where he felt like turning around and going back home, so hopeless did the situation appear.

The main and river pumping station of the water works were built

CINCINNATI'S MAIN PUMPING STATION AT EASTERN AVENUE, JANUARY 27, 1937
River stage 79.8′

SAME STATION, FEBRUARY 1, 1937
River stage 70.5′

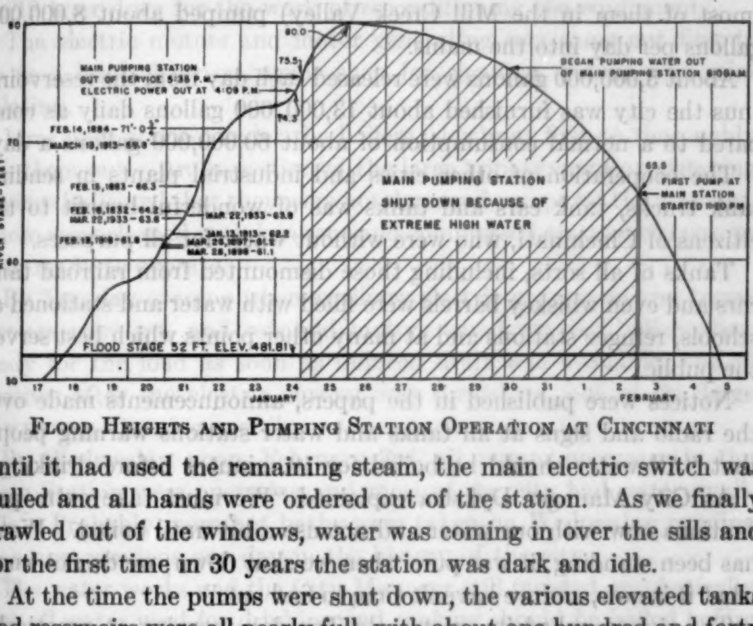
MAIN ENTRANCE TO PUMPING STATION, FEBRUARY 1, 1937
Note high water mark

KELLOGG AVENUE AT CONGRESS, CINCINNATI, FEBRUARY 1, 1937
Note size of material carried by flood

in 1900–1907 and were constructed at an elevation which was considered to be well above any known flood level, the stage of 1884 being referred to in particular. The floor level of the main pumping station is about flood stage of 72 feet which was reached early Saturday morning. On "Black Sunday" at 5:30 P.M. the river had reached a stage of 75.5 ft. Water was coming in through conduits and tunnels faster than all the regular and emergency sump pumps could remove it.

PUMPS CLOSED DOWN

When it was seen that water would soon reach the air valves of the triple expansion pumps and shut them down, orders were given to draw the fires under the boilers, the last pump was allowed to run



FLOOD HEIGHTS AND PUMPING STATION OPERATION AT CINCINNATI

until it had used the remaining steam, the main electric switch was pulled and all hands were ordered out of the station. As we finally crawled out of the windows, water was coming in over the sills and for the first time in 30 years the station was dark and idle.

At the time the pumps were shut down, the various elevated tanks and reservoirs were all nearly full, with about one hundred and forty million gallons of water in storage. To conserve this supply all reservoir valves were closed and only opened for short periods morning and evening.

Cincinnati is so hilly, however, that those on the hilltops in the various service districts did not get the benefit of any of this rationing.

An emergency holiday was declared by the City Manager and every person not having urgent reasons for being in the down town section of the city was requested to remain at home.

A Disaster Committee, consisting of city officials and headed by City Manager and the Mayor was quickly established. Broad powers were granted to this committee and all matters were dealt with by this body, which was authorized to issue and enforce necessary mandates.

A city wide holiday was declared that closed all stores, factories, theatres, etc. and tended to reduce water consumption to not much more than personal needs.

EMERGENCY SUPPLIES

Immediate steps were taken to make temporary connections to all available emergency supplies, and in a day or so various industrial plants and neighboring towns having their own deep well supplies (most of them in the Mill Creek Valley) pumped about 8,000,000 gallons per day into the mains.

About 5,000,000 gallons were released each day from the reservoirs, thus the city was furnished about 13,000,000 gallons daily as compared to a normal consumption of about 60,000,000 gallons a day.

The cooperation of other cities and industrial plants in sending tank trucks, tank cars and tanks was of wonderful benefit to the citizens of Cincinnati, who were without water for all purposes.

Tanks of all sorts, including those dismounted from railroad tank cars and even whiskey barrels were filled with water and stationed at schools, refugee stations and at many other points which best served the public.

Notices were published in the papers, announcements made over the radio and signs at all tanks and water stations warning people that "All water should be boiled for 10 minutes before drinking."

As City Manager Dykstra explained "We must take extra precautions now with our water and not use a bit until boiled. Water has been standing; it was pure when we shut down; we do not know what it is now, and we haven't time to find out."

The river reached its crest early Tuesday morning at practically 80 feet, and careful calculating and plotting indicated that it would be back down to 76 feet sometime the following Saturday.

RESTORATION OF SERVICE

Local contractors were called in, manufacturers' representatives consulted and plans for the resumption of pumping made. A broken concrete and rock road, or causeway, 8 feet deep was built

through the flood water over paving, tracks and walks of the street in front of the station at an elevation which would enable us to move equipment and men into the station from the hillside across the street. A winch and heavy cable allowed trucks to be moved up and down the hillside.

Early Saturday morning with water still coming in through the windows, but receding fast, the first gasoline trench pump was started, and soon we were pumping water out of the flooded station at the rate of 10,000 gallons a minute. The roar of these pumps was pleasant music to the men who were waiting to get back into the station to work.

The dewatering of the station was handled by outside contractors, our own force being detailed in shifts, some on 8 hour duty, others on 12 hour duty for the work of reconditioning the equipment.

The electric motors and motor generating sets came out first to go to a local electrical repair shop for cleaning, baking and reinsulating.

Fires were started under the boilers, slowly at first to thoroughly dry them out. An inspection of the large triple expansion pumping engines indicated that they were not damaged except for the bearings. These were cleaned with kerosene and compressed air, and the pumps were ready to operate.

By Tuesday evening when auxiliary electric generators and transformers were set, and repaired motors wired up, the boilers were ready for the load as soon as induced draft was available, and 30 minutes after the electric current was turned on, one of the large pumps was "turning over."

By Wednesday noon, February 3rd, all pumps necessary in the Main Station were operating and most of the city had water available. Probably more hot baths were taken on Wednesday evening than any previous one day in the history of the city.

The water works and the City Manager still insisted emphatically that all water used for drinking and cooking should be boiled before using and this warning continued daily in the newspapers. In cooperation with the U. S. Public Health Service, plans were made to apply heavy doses of sterilizing chemical to the water being pumped. Tests were made of samples collected from hundreds of points on the distribution system, some of which showed exceptionally high percentages of coliform organisms.

This contamination was caused to a great extent by back syphoning of water from toilet fixtures. The pollution was so concentrated in some spots that tests showed the existence of both Coliform organisms and chlorine residual. Calcium hypochlorite containing about 70 per-cent available chlorine was used for this sterilization, the average chlorine dose applied was about ten times normal, so that a residual of 3 p.p.m. was maintained rather than 0.3 p.p.m. in the filtered water.

The order to "Boil all drinking water" was not removed until chlorinated water had been obtained at the extreme outer limits of the distribution system.

We are very glad to report that there was not a single case of typhoid or other intestinal trouble in Cincinnati due to the flood or the unusual water supply conditions.

The emergency holiday for business was discontinued on Thursday, February 4th, and on Friday, all restrictions on hours of business and industry were removed.

FUTURE STEPS

The question as to what steps should be taken to offset any possible future shut downs due to floods, is a very serious one and is to be given every consideration. Our thought up to the present time, however, is more toward the construction of future works or additions to the present pumping installations so constructed that operation will be possible during any flood of like proportions, or in fact, any flood of considerably greater proportions.

We feel that it is rather impractical to try to protect the present works from flood by means of coffer dams or flood walls, bearing in mind the fact that our pumping stations are so close to the river that any such construction may result in an uplifting action on the station buildings. Such flotation might result in the disruption of the operation of the stations and put them completely out of service for a considerable period.

The actual damage done to stations and machinery by flooding was relatively small and we were able to start up again very quickly after the water had subsided.

We feel, therefore, that if auxiliary pumping units can be installed in such a manner that they can be operated in spite of any high water, that we can just allow the present equipment to become flooded and operate the auxiliary units, during an extreme emergency period.

At the main pumping station, the best solution would appear to

be the installation of a vertical centrifugal pump electric motor driven, with the motor high above even a 100 foot stage of the river. This motor could be operated by remote control, and it is possible that the stand-by or ready to serve charge for power could be eliminated by its use during normal periods to consume only off peak current under the control of the power company.

We also have plans for additional pumpage and mains, which would supplement the main station output, and which would be above any possibility of flood damage.

These plans were in the hands of the PWA authorities in Washington in November, 1936, and have but recently been recalled by our own office with every prospect of proceeding without the PWA grant or coordination. We contemplate the construction of a 20 M.G.D. pumping station and about 18 miles of large feeder mains, leading direct from the filtration plant to the hilltops skirting the city.

Had this project been in service during the flood, our situation would have been considerably different.

Future plans include the construction of storage reservoirs in the distribution system, which will increase our filtered water storage from 140 million gallons to 500 million gallons.

THE LOUISVILLE WATER COMPANY AND THE 1937 FLOOD*

By L. S. Vance

(Chief Engineer, Louisville Water Co., Louisville, Ky.)

Prior to our recent inundation, the flood of 1884 had been the dating incident of all river happenings and was considered as the never to reoccur maximum in so far as Louisville was concerned. The 1936 "flash" flood of Pittsburgh did not seem within the realm of possibility in this part of the Ohio River basin.

The river pumping station buildings in present day use had all been constructed subsequent to 1884 and were designed and built to withstand and continue to operate thru a reoccurrence of that much water. The periodical flood periods had been met so often that they were considered only as an inconvenience to be borne as they occurred.

Sometime about Wednesday, January 20th, 1937, the forecast of a flood exceeding the '84 crest was received and steps were taken in an attempt to protect the river pumping station against higher water. Bulkheads were installed in the steam pipe tunnels to protect the boiler house basement and around the pipe openings thru the pump station wall.

SERVICE INTERRUPTED

On Thursday, the 21st, telephone communication with the river station was lost, the wires having been torn down by a floating house. The only means of communication then was notes and word of mouth by skiff, which made more or less regular trips to and from the station with the different station operating crew shifts. Friday morning it became evident that radio would be the only possible means of maintaining the absolutely necessary contact. And thru the foresight, level-headedness and red tape cutting attitude of the officers in command of the 138th Field Artillery of the Kentucky National Guard, three hand operated generator field radio sets with

*Presented at the Buffalo Convention, June 9, 1937.

crews were obtained. One was set up at the down town office, one taken to the river station by boat and one to our Crescent Hill station. It was thru these sets and considerable physical labor at the hand generators by the operators that communications were maintained. However, as the days passed, radio contact with these sets at night was more difficult, due probably to atmospheric changes. Later two larger two way voice sets with operators were supplied by the 1st Cavalry Division U. S. Army of Fort Knox. These sets were reliably effective until the high tension transmission lines which pass very close to the river station were energized. From that time on, radio communication on the wave band of those sets was not feasible. Shortly after this the Telephone Company strung an emergency wire along fence posts on poles to trees to poles over the still flooded flood plane to the station and normal telephone service was maintained from then on. Early that Friday morning the Power Company asked us to release them of our electric pump load, they too were having their troubles. We reverted to steam power pumping as soon as possible.

As the river level rose rapidly that Friday afternoon and evening the problems of not anticipated and unforeseen conditions and possibilities began to make themselves felt. The 1884 record had been passed shortly after noon and a crest of 52 feet forecast for sometime Sunday. The river continued to rise rapidly. The river stage was 47 feet at 5:45 P.M. and 48 at 9:30, a rise of about three tenths per hour.

At 9:30 P.M. Friday, the 22nd, the boiler house bulkhead let go and in a very few minutes the boiler house basement with ash disposal track and equipment was flooded, just prior to this time the ash hopper gates of the boilers had been opened to allow the ashes to spill out and pile up as they may.

By this time the bulkheads around the pipe openings of the pump house were also leaking but the steam sump pump was able to hold this leakage down. The steam pipes, however, from the boiler house to the pump house were then under water;—river water and cold. The condensing effect of this flooding on the steam piping was felt very shortly. The steam pressure at the throttle of the turbo centrifugal pump dropped gradually but steadily. Until at 3:15 A.M. on Saturday, the 23d, with a stage of 49.3 feet the pressure at the throttle valve was only about 95 lbs. per square inch and pump output down to 5 m.g.d.

At about 2:30 A.M. that morning, when it became definitely evident that the river station would go out of operation, the expedient of rationing the remaining water supply to the city was decided upon. Our Crescent Hill station, pumping filtered water to the city and elevated storage reservoir was to shut down at 9:00 A.M. This delay was to provide ample time to notify the consumers thru the newspaper and radio of the necessity. The city, until after the emergency, was to be supplied thru the operation of the Crescent Hill station only two hours each day from 8:00 to 9:00 o'clock in the morning and from 4:00 to 5:00 in the afternoon.

At this same time the elevated storage reservoir was shut off to conserve for dire emergency the 25 million gallons retained in it.

A list of gate valves along Beargrass Creek, to be closed to separate the higher elevations of the city from the down town area, was made up and given to our service foreman. This was planned in an attempt to conserve as much water in the distribution system between pumping periods as possible in order to obviate the necessity of filling an empty pipe system at the start of each pumping period. It was arranged that the service foreman was to open one of the 48-inch division gates at the beginning and close it at the end of each pumping period, in the morning and afternoon. These valves were closed, even though some were already covered by flood waters.

Another line of gate valves along the then edge of the flooded area in the western part of the city was listed. Only the larger valves of this group were closed to prevent excessive loss of water in case of main breaks. The smaller valves on the list were not operated as it was learned that refugee centers and emergency hospitals were expected to be maintained even in this area, thru the then expected flood.

The closing of these valves in the distribution system was not accomplished until the afternoon of Saturday, January 23d.

In the meantime, the river station pump was shut down at 3:32 A.M. and the last of the steam from the boilers and flooded steam pipes used to lift the large electric motor from the 60 m.g.d. centrifugal pump to a level above the operating floor and above the, at that time, expected crest. All other possible precautions for the protection of the station and equipment were made with the station crews remaining energy and steam and power.

At the time of shut down of the river station (primary or so called low lift plant) there were about 75 million gallons of water in the sedi-

mentation basins, of which about 30 million could be utilized without by-passing the coagulation basins and there were about 10 million gallons in the filtered water reservoir or clear well which could be used. This, plus the water in the elevated storage reservoir, should provide about ten days of rationed service assuming a rate of consumption of 4 to 5 million gallons per hour. There was no definite basis for an assumed consumption of 4 to 5 millions per hour. Many homes we knew would be and were evacuated during our off-pumping time, leaving their faucets open. Breaks in piping of flood moved houses would be another source of unpredictable water loss.

The operating crew abandoned the station by way of the steamboat Duffy sent to pick them up about 2:00 P.M. on Saturday, January 23d. No men were allowed to remain at the station.

LOUISVILLE RIVER PUMPING STATION—INTAKE TOWER. 1937 FLOOD AT APPROXIMATE CREST

INTAKE TOWER AT NORMAL RIVER STAGE

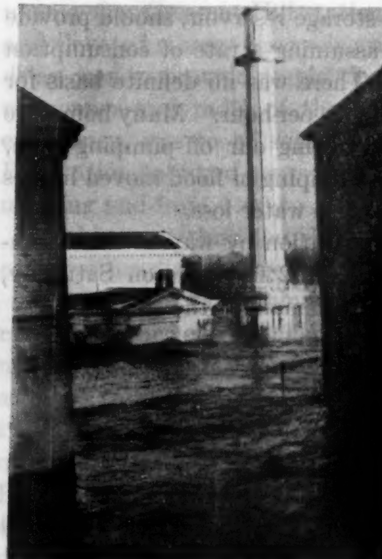
A more down-hearted and dejected water works organization, I think, could not be found in the whole country that Saturday night.

EMERGENCY OPERATION

About 5:00 A.M. the next morning, after several telephone conferences, the plan of using steam from the boilers of a steamboat to operate the triple expansion fly wheel type of pumping engine was enthusiastically entered into by every one.

An operating crew with necessary supplies and part of the necessary equipment was assembled; the tow boat in the meantime was being prepared; a barge of coal obtained and the outfit started for the pumping station about noon. Flexible steam hose from the Louisville & Nashville Railroad shops followed by Coast Guard Boat. The tow boat arrived at the station about 3:00 P.M., being

delayed by fog, and thru the resourceful expedients of welding nipples into steam headers, rearranging elbows and tees in the steam



ORIGINAL PUMPING STATION AND STANDPIPE AT APPROXIMATE CREST OF 1937 FLOOD

SAME VIEW AFTER FLOOD HAD SUBSIDED

RIVER STATION BOILER HOUSE WITH 3½ FEET OF WATER OVER FLOOR, AT FLOOD CREST

STEAMBOAT MOORED TO THE DOWNSTREAM SIDE OF PUMPING STATION DURING FLOOD CREST. SUPPLYING STEAM FOR PUMPS

lines, robbing steam heating systems of needed unions and fittings, had steam on the 24 m.g.d. pump and water started up the hill to the reservoir at 6:00 P.M.

On arriving at the station, the original plan of operating the 30 m.g.d. triple had to be abandoned as the integral air pump was already flooded, flood waters being only about six inches below the operating floor.

On starting the 24 m.g.d. pump in the number two, a wet well station, considerable trouble was experienced with some of the 3″ x 8″ plank flooring of one of the lower balconies floating into the spokes of the fly-wheel. These boards were broken into small pieces, without damage to the fly-wheel but with considerable damage to the guard rails and the otherwise staunch nervous systems of the operating engineers and oilers.

The flexible steam hose, until replaced, was a constant source of danger and trouble. The boiler pressure was 250 lbs. per square inch but steam line drop thru the relatively small pipe and hose cut this to about 125 lbs. per square inch at the pump throttle.

Except for the interruptions due to steam hose trouble and some air pump trouble, the pump operated continuously from then on, not at full rated speed or capacity but at about a rate of 18 m.g.d.; enough that during the following days the sedimentation basin levels climbed daily and later the rationing periods could be safely extended.

In the meantime the river continued to rise. At its crest on Wednesday, January 27th, there was 4.5 feet of water over the operating floor which meant that the main crankshaft bearings of the 24 m.g.d. pump had about 14 inches of flood water over the bearing caps. The bearings did not heat up with their water lubrication and water cooling but starting the pump after an unavoidable stoppage became more and more of an uncertain job at each trial.

The reliability of the hastily moved old air pump being extremely uncertain, it became necessary to obtain from the Louisville & Nashville Railroad an air pump from one of their locomotives, then out of use due to the flood, to provide a more reliable air supply for the poppet valves and discharge chambers. Disconnecting, moving, transportation by hand, truck, row-boat, motor-boat and hand again of such heavy and bulky piece of machinery, now along with other things accomplished by other organizations has proven that there is nothing that really cannot be done.

Later oil was actually gotten to the main bearings of the pump while still under water thru the use of high level oil cups and long feed pipes providing enough static head of oil to overcome the head of

water in and on the crankshaft bearings. The eccentric bearings and end crank bearings were oiled thru the use of arm-pit wading boots borrowed from a minister of the gospel whose religious faith encompassed total immersion. Hunter and fisherman arm-pit waders were not available since the owners were engrossed either at boat stations or elsewhere.

A clearer picture of the sequence of events and the difficulties of operation can be obtained by quoting excerpts from the notes made during this period of operation.

January 26, 1937—9:33 A.M. Contact established with boat and river station by radio. (No contact during the night.)

10:00 A.M. Expect crest at Louisville to be 57.6 feet.

10:15 A.M. From Payne (Supt. of Pump Stations) "Pumping 20 m.g.d. Water at window sills. Send meat, flour, bacon, eggs, clothes, shop taps. Men want to go home for a while."

11:15 A.M. Radio request from WHAS—request asks motorboat for Louisville Water Company to carry 7 men and provisions for pumping station to land on Zorn Avenue. This boat to be assigned to Louisville Water Company for their use.

11:00 A.M.—Thru WHAS. River stage 56.9 feet. Rain or snow expected.

12:35 A.M. Water stopped. (That is stopped coming into the sedimentation basin from the river pump station.)

1:00 P.M. Water started again.

2:10 P.M.—30 m.g. available now for rationing without by-passing coagulation basin and exclusive of Cardinal Hill Reservoir (elevated storage).

3:00 P.M.—Called Tate of L & N at Smiley's House (L & N Chief Engineer) in regard to air pump from locomotive in East Louisville R. R. Yards. Talked to Parsons, Supt. of Transportation. He arranged that Mr. Gallagher, Electrical Engr. of L & N would come to the Crescent Hill Station to pick up our machinist and they would go to East Louisville to get 7½ air pump.

5:00 P.M. to Payne—Air pump being obtained.

As the superintendent of pumping stations said later "through my imagination and the hard work of the men, we were luckily able to keep going."

By Sunday, January 31st, enough had been gained in the sedimentation basins thru almost continuous operation of the primary pump station that the rationing pumping time was increased to two hours

in the morning. Later this was lengthened to four hours in the morning then ten hours thru daylight on February 3rd, and finally when we had restarted our own steam generation at the river station, on to 24 hour service on February 4th.

RESUMING REGULAR SERVICE

The restarting of our own boiler plant as the flood waters receded and successively uncovered the grates, boiler room floor, etc. was a series of disappointments. One night and day of freezing weather had cracked pipe fittings, frozen chain grates, left frozen mud and innumerable other annoyances. One chain grate stoker drive worm gear required electric welding; the line shaft of the stoker had to be oiled from a small row-boat operated in the boiler house basement; another stoker partly dismantled due to broken links; steam pipe insulation dried out and generators and engines cleaned and dried thru continuously applied heat and circulating air. These successive problems were met and dealt with by a tired and by that time successful operating crew.

The turbo centrifugal pump, with the aid of a representative from the manufacturer, was cleaned and prepared for operation without night work in three days. It was put in operation at noon of February 11th.

On February 12th, the L. & N. R. R. section crew started the work of repairing the washed out portions of our switch track over which coal is brought to the station.

As soon as 24 hour service was restored even at reduced operating pressure, the line of closed gate valves in the city were opened to restore as soon as possible normal water service over the entire distribution system. It was found necessary during the period of one and two hour rationing pumping to bleed some water from the elevated storage reservoir. The area farthest from the high lift pumping station did not receive water until this was done due to the relatively short pumping time and the inability of the system to force out the air from the empty mains in such a short time.

Normal operating pressure was not fully restored to the distribution system until late in the month of February. The underlying sand and gravel of the prehistoric river bed, over which the major portion of the city is built, on inundation by the flood waters, compacted, shearing catch basin leads and sewer connections and causing many cavities under the undisturbed street surfaces. The internal

pressure of flood back-waters on old single row radial brick sewers caused failure and subsequent collapse of street surfaces and breaking of gas and water pipes, telephone and power and light conduit systems. To prevent danger to workmen in such cavities and to protect buildings in case of possible subsequent water pipe failures, relatively long lengths of water mains affected were isolated by closing gate valves, feeding the consumers in such sections thru only partly opened single valves. Fire department and salvage corps were notified of such shut offs so that in case of fire such closed areas could be quickly opened.

During the whole emergency period, the difficulties of purification plant operation under intermittent demand conditions and difficult gravity head conditions throughout this purification operation were met without any faltering or question as to the assurance of a safe product. For safety from pollution after pumping to the submerged distribution system the residual chlorine was maintained at five tenths part per million during the emergency period. Only one or two of the many daily samples taken and hurriedly checked showed a doubtful or suspicious rating.

Enough cannot be said in praise and in thanks to the L. & N. R. R., the other utilities, the Louisville Gas & Electric Company especially, and the Telephone Company, private firms, other Governmental Agencies, the Regular Army and National Guard and private individuals for the ever ready help and cooperation in such an emergency. Without such aid and unstinted effort, the complicated operations which were necessary to carry on could not have occurred with anywhere near the degree of success as actually did occur.

Discussion by W. H. LOVEJOY.[1] The city of Louisville is 156 years old, having been founded in 1780. During this period the city has experienced many disasters such as wars, tornadoes, epidemics of typhoid and cholera and last, but not least, floods. Of all of these calamities, river floods are probably the most frequent, the most destructive to property and, withal, the most to be feared.

There are practically no authentic records regarding Ohio River floods prior to about 1873. However, history does give us a rather lurid account of a super flood in this valley during the time of DeSoto,

[1] Excerpt from a paper presented at the Illinois Section Meeting by W. H. Lovejoy, Superintendent of Purification, Louisville Water Company, Louisville, Ky.

although from this we have no figures with which to compare these earlier floods with those of the present day.

In the 77 years since the Louisville Water Company was established in 1860, the river has attained the nominal flood stage of 28 feet at least, once every year and, in some years, it has occurred two or three times. The greatest floods recorded in this 77 year period are those of 1884, 1913 and 1937.

FLOOD CRESTS OF 1884, 1913, 1937

At present the normal stage of the river at Louisville is called 17 feet, corresponding to 420 feet elevation above sea level. The 1884 flood reached a crest of 46.7 feet at Louisville; the 1913 flood reached 39.1 feet and the 1937 flood reached 57.1 feet. Therefore, the 1937 flood topped that of 1884 by 10.4 feet and that of 1913 by 18.0 feet. This excess of 10.4 feet over the highest previous river in 1884 explains the flooding this year of parts of the city and of utilities' equipment which were never before affected. It is only natural that the city and the public utilities should have planned and built their facilities on the basis of past river experience, which, in this case, means the 1884 flood crest as the maximum.

ELEVATIONS OF CITY AND OF UTILITIES' PLANTS

The lower plane of the city, which was flooded, lies at an elevation varying from 448 to 464 feet above sea level. The 1884 flood reached 450 feet, thereby hardly affecting this area at all. The 1937 flood, reaching 460 feet, put from 2 to 12 feet of water over this area with the exception of a few scattered areas which remained dry.

Both the Water Company and the Electric Company built their plants with operating floors at elevation about 455.5 which would protect them against a flood some 5 feet higher than the 1884 level. Both of these plants had about 5 feet of water over their floors. The question here arises: How far would it be justifiable for the city and these utility plants to go in the way of expenditures for future protection against floods of either this or even greater heights? Army Engineers estimate that another flood of this or greater crest is not liable to happen again in from 500 to 1000 years, based on the law of probabilities.

PICTURE OF CONDITIONS IN THE CITY

Imagine, if you can, a city of 330,000 population, covering an area of 40 square miles, having 60 percent or 24 sq. miles of its business and

residential area covered with from two to ten feet of flood water. About 200,000 people had to be evacuated hurriedly from the flooded districts by every conceivable means of transportation, including railroad trains, trucks, passenger automobiles, canoes, rowboats and motorboats. These refugees were taken to higher ground in the city or, in many cases, to points in Kentucky, Indiana and Tennessee. All factories, stores and office buildings were closed for periods of from two to four weeks. Hotels and apartment buildings were without heat, light and elevator service. Street car service was suspended because of power failure; buses and cabs could not operate through the flooded streets. A pontoon bridge a mile long had to be built to accommodate the movement of refugees and others from the flooded district to the higher level of town. In fact, all normal business and other activities were completely paralyzed for two or three weeks. All public agencies including police, firemen, city officials as well as every other individual in the city was busy either looking after his own family and property or in trying to help others who were in greater danger.

Had the local Weather Bureau and the Army Engineers been able to forecast more accurately the probable crest of the river, as they have done previously during flood periods, it would have aided both householders and utilities by giving them more time to move and save much property and equipment. This would, also, likely have made it possible for the utility plants to have made temporary arrangements for continuity of service. However, in the light of weather conditions existing at that time, it is no wonder that all estimates of the crest failed.

DATA ON THE OHIO RIVER AT LOUISVILLE

The normal annual rainfall in Louisville is 42.84 inches. During January, 1937 the city received 19.17 inches of rain. Rainfall over the entire watershed of the Ohio approximated these figures. After the river reached the expected stage of about 39 feet on January 21st, we had four consecutive days of rain totaling 9 inches which raised the stage about 3 feet a day for the next six days to its crest of 57.1 feet on January 27th. From this date the river started to fall slowly and only reached normal stage on February 8th. Thus, it required 17 days to reach the crest and 12 days to recede back to normal.

At normal stage the river at Louisville is from ¾ to 1 mile in width at various points. During the flood it expanded to from 3.0 to 25

miles in width. Velocity readings and flow tests made by the U. S. Engineers show that at the crest the current was 6 miles per hour and the flow averaged 1,250,000 sec. ft., equivalent to 9 mg. per second or about 800 billion gallons per 24 hours. In other words, every five seconds enough water passed our river pumping station to supply the city of Louisville at its average rate of consumption of 45 mgd. This flow exceeded the maximum flow during the 1913 flood (700,000 sec. ft.) by about 70 percent.

This excessive flow, coupled with the highest known stage, is not to be wondered at when we consider that the river was attempting to carry off 15 inches of rainfall in about 16 days, equivalent to over one-third of the normal year's precipitation. It should be remembered, also, that this amount of rain fell over practically the whole of the 150,000 square miles of the river's watershed.

LOCATION AND ELEVATIONS OF WATER WORKS PLANT

Our low service or raw water pumping plant is situated on the south bank of the river about three miles up river from the city. This is the only part of the plant that was directly affected by the flood. The remainder of the plant units, including the preliminary basins, coagulation basins, filter plant and high service station are all located $2\frac{1}{2}$ miles inland and on a plane about 100 feet higher than the river station.

WATER SUPPLY PROBLEMS ARISE AS FLOOD PASSES 1884 LEVEL

During the first week of the flood period from January 14th to January 21st, as the river level rose from 20 feet up to 40 feet, the Water Company took only the usual precautions of arranging boat service and supplies for the operation of our river plant. Up to that time unusual crest conditions were not prophesied or expected by us and we planned on operating just as had been our custom once or twice every year for the past 60 years. However, on January 22nd all of our previous plans, predictions and hopes had to be discarded as the river went over the 46.7 feet crest of the 1884 flood, rising at the rate of 0.2 feet per hour. This day was also the turning point in the hopes and fortunes of the other utilities and for the inhabitants of the city.

On this day the Electric Company's power plant went out of service, cutting out electric pumping at our river station and causing us to go back to steam operation immediately; the artificial gas plant

went out and the city was placed on natural gas; movie theaters and schools were closed; 800 telephones and the local radio stations were put out of service by power failure. Railroad service in and out of the city was cut off; street car, bus and taxi service was stopped by flooded streets. Flooded basements put out fires in boilers in hotels and office buildings, stopping practically all office and factory work. With communication restricted, transportation paralyzed, and with boats plying the flooded streets rescuing people and goods, confusion and terror naturally followed.

On this day, also, things began happening in water works circles. Previous to this time many of the water works employees had become marooned in their homes in the flooded districts and could not get to work, either because of lack of transportation or because of the necessity of attempting to save their families and property. The absence of some of these men hampered routine operation and our extra flood preparations as well, causing the rest of us to each assume two or three men's work for the next ten days. Eighteen to twenty-four hour stretches of work were the rule for all of us during this period.

The events which followed have been recorded by Mr. Vance. As he indicated the rate of application of chlorine was increased to the point that the safety of the water supply was assured and the consumers were amply protected during the flood period and during the time when normal living conditions were being restored in Louisville.

THE EVANSVILLE WATER WORKS AND THE 1937 FLOOD*

By Louis A. Geupel

(*City Civil Engineer, Evansville, Indiana*)

General water works engineering practice takes cognizance of the facts that a most disastrous flood passed down the Ohio River Valley in January and February, 1937, and acknowledgment must be given that all previous basic design data with reference to high water elevations for new water works construction and improvements to existing plants must be and are from this time, revised to higher elevations in the Ohio River Valley and its tributaries.

This brief discussion deals with the isolated hazardous conditions encountered and the restoration repair work performed under difficulties at the Evansville municipal water plant.

Evansville, Indiana, with its population of 105,000 is a very busy industrial city, located peculiarly around the outer edge of a crescent reverse bend of the Ohio River. The width of the Kentucky peninsula due west from the water plant is only 4,800 feet, and the distance between the two channels of the Ohio River at this point is only 7,200 feet. The peninsula land is flooded at river stage of 40 feet.

A normal river stage at Evansville is maintained at about 9 feet. For engineering information, zero of the river stages given in this discussion is 329.2, U. S. Geodetic Datum. At the Evansville gauge, the flood stage of 1884 was 48 feet, in 1913 the stage was 48.4 feet, and the official river stage in January, 1937, on the 31st, was 53.75 feet. The river stage at the water plant one mile upstream was recorded at 53.96 feet.

THE WATER PLANT

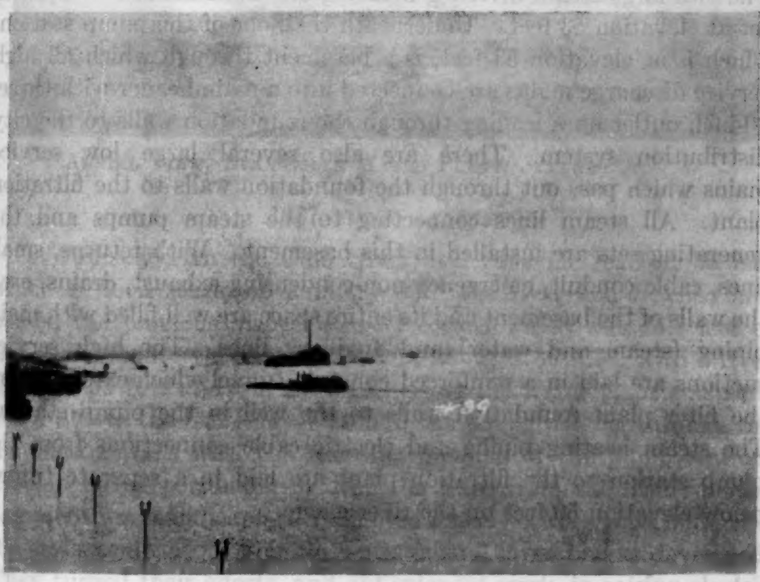
The Municipal Water Plant is located on a raised mound about 2,000 feet by roadway to the populated part of the City. The area between is flooded at a river stage of about 44 feet. The water

*Presented at the Buffalo convention, June 9, 1937.

EVANSVILLE RIVER FRONT, MAY, 1936
Before improvement project was started

RIVER FRONT, NOVEMBER, 1936. AERIEL VIEW SHOWING IMPROVEMENT COMPLETED
Water plant at extreme right of picture

RIVER FRONT, LATE 1936
Water plant in distance center



SAME VIEW AT HEIGHT OF 1937 FLOOD

plant includes the pump station with its wing and boiler room in one structure and the filtration plant with its settling basins in a second structure. The plain concrete foundations of the pump rooms extend to elevation of river stage 53 feet, but to only the stage of 52 feet in the boiler room. The floor line of the filtration plant building, which is the top of the reinforced concrete walls, is at an elevation of 55 feet on the river gauge. Both buildings are located on the same raised earth mound and are about 65 feet apart with ground line and driveways in between at elevation 50 to 50.5 feet. The pump station has a stone well 53 feet in diameter and about 61 feet deep, the bottom of which is about 8 feet below zero on the river gauge. Three motor driven, low service, centrifugal pumps of 8, 12, and 20 million gallon per day capacity are set on a structural floor in the well, with floor line elevation of 4 feet on the river stage. The two triple expansion steam Holly high service pumps of 10 million gallon per day capacity are set on floor line 53 feet, the two 15 million gallon turbo centrifugal high service pumps held for emergency use are set on floor line about 40 feet, and the new 20 million gallon steam turbine driven high service pump installed in the new wing is set on foundation with elevation of 40 feet on the river gauge. The two large steam driven generating sets are installed with bases set at elevation 53 feet. Underneath the floor of the pump station, which is at elevation 53 feet, is a basement through which all high service discharge mains are connected into a main header with three, 30-inch outlet lines leading through the foundation walls to the city distribution system. There are also several large low service mains which pass out through the foundation walls to the filtration plant. All steam lines connecting to the steam pumps and the generating sets are installed in this basement. With returns, small lines, cable conduit, emergency non-condensing exhaust, drains, etc., the walls of the basement and its entire space are well filled with main piping (steam and water) and auxiliary lines. The high service suctions are laid in a reinforced concrete tunnel which extends from the filter plant foundation walls to the well in the pump station. The steam heating piping and electric cable connections from the pump station to the filtration plant are laid in a separate tunnel below elevation 50 feet on the river gauge.

RIVER FRONT IMPROVEMENT

As a matter of general interest of flood effects and damage the City recently completed a very popular Public Parks River Front

Improvement Project in December of 1936. This project in brief includes a boulevard 80 feet wide extending for 6 squares in front of the old river front business district with a reinforced concrete river wall, river steamer landing and interconnecting concrete roadways. From this area Sunset Park river bank was leveed and the bank sloped and protected with riprap to the revetment of the water plant mound. The River Front Improvement Project extends from the water utility garage, 5,200 feet upstream to the water plant. With the plan of park beautification this whole area is now laid out as Sunset Park, which when completed places the city water plant at the upper end of a municipal river park. The top of the river bank levee is 25 feet wide and was constructed for a river stage of 49.4 feet or one foot above the 1913 Flood.

AERIEL VIEW, EVANSVILLE WATER PLANT, JANUARY 28, 1937

1937 FLOOD LEVELS

On January 11th the Ohio River at Evansville reached 35 feet which is flood stage, on January 23rd the river had reached and passed the previous highest stage recorded which was 48.4 feet of the 1913 Flood. On January 26th at about 8:30 A.M. with a river stage of 52 feet and the river still rising the water plant was shut down due to the bad leakage around the piping passing through the foundation walls with the resulting flooding of the pump station. The operating personnel, fighting the leaks from the inside of the basement was handicapped by limited space between pipe lines, and the walls and had to give up when several large breaks developed. They turned their efforts, and did splendid work, in raising electric motors out of the wells and pits and setting them on blocking above

55 feet level. As the water plant was isolated and surrounded by water at elevation 45 except the connection with the new river front levee, only limited preparation had been made to fight the leaks from the outside, except to brick up doorways and sandbag the coal conveyor openings.

EMERGENCY COMMITTEE

On January 26th, after the shut down of the plant, Mayor Wm. H. Dress requested the superintendent and his operating personnel to obtain a much needed rest and on the same day appointed a special water committee with power to act and with orders to place the water plant back into service as soon as possible. This committee included Mr. Edgar Traylor, an Evansville contractor experienced with Ohio River construction work; Mr. Charles Streithof, Superintendent of the Water Plant; and Mr. Louis A. Geupel, City Civil Engineer and formerly Chief Engineer, State Board of Health of Indiana. Mr. C. B. Burdick, Consulting Engineer, was requested to come to Evansville at once. Immediately two major problems of obtaining water were faced and the method of procedure laid out as follows:

1. As the question of damage, and as the work of dewatering the pump station were indefinite problems and dependent on many unknown conditions, it was decided to connect every privately owned industrial well supply to the City system either by installing cross-connections or by pumping through fire hose lines back through fire hydrants. This work was outlined by the City Engineer but the actual work was performed by Mr. Ed Kinney, Indiana representative of Wallace & Tiernan, Mr. James A. Bruner, City Building Commissioner, and Mr. George Johnson, City Plumbing Inspector. These men did splendid work and by January 28th, 3,000,000 gallons per day of well water were pumped into the City system. By January 31st, 5,000,000 gallons per day were pumped, and on February 1st an additional 3,000,000 gallons were available. At this time the water plant went back into service and the well water was not needed.
2. On January 26th and the morning of the 27th, floating equipment was assembled, thousands of sandbags filled, and portable gasoline pumps, together with all kinds

of tools, were transported by barges to the isolated and flooded pump station. Floating docks were anchored and runways constructed to the building. On January 27th, the sandbags cofferdams were started around the places of worst known leakage.

The pump station with its low service well 61 feet deep was filled and on January 31st when the crest of 53.96 was reached at the plant, about 12 inches of water was on the main pump floor and the surface covered with a heavy coat of lubricating oil. There was over 2 feet of water in the boiler room. Every one who worked at the plant was in hip boots and a strict watch was kept over the work with regard to safety of the men as one knows there are many openings and dips in a water plant pump room and boiler room floor if gratings have been removed. By January 28th, four portable gasoline pumps, which included an 8-inch, 6-inch and two 4-inch gasoline motor driven pumps were in operation, pumping water out of the building.

Steadily through all shifts, several hundred men from the W.P.A. forces under the direction of superintendents and foremen who volunteered from many contracting firms in the city, filled and stacked sandbags around the outside of the building. Shower room drains, toilets, floor drains in the boiler room, sinks, and all openings were sealed with heavy corrugated paper sheets weighted down with sand bags. At all times of the day and night a member of the committee was on the site or in close touch by telephone with the foremen on the work to assist and direct operations. All operating equipment was taken over by the superintendent and his personnel as quickly as dewatering permitted. All questions of procedure were discussed with Mr. Burdick who was on the site as consultant.

On January 30th the major leakage was controlled and the water lowered 10 to 12 feet in the building sufficiently to fire the boilers and turn over the 75 Kilowatt generator set and light was available through a temporary system for night work.

On January 31st as explained previously, the crest of 53.75 feet of the flood was reached and the water was up

to the bottom of the stone sills of the windows of the buildings. Water was leaking through the cracks in the brickwork but two pumps were handling the leakage in good shape. On February 1st, with the river stage at 53.7 the Holly 10,000,000 gallon per day triple expansion steam pump was placed back in service pumping turbid water from the clear well of the filtration plant containing 4 to 5 parts per million of free chlorine, to the City Distribution System. It is to be noted that the plant flooded out with a river stage of 52 feet goes back into continuous service of pumping with a river stage of 53.7 feet.

While the dewatering work was going on in the pump station the Committee realized the difficulty of dewatering the low service pump well 61 feet deep. A 10-inch diesel gravel pumping dredge and a 12-inch steam gravel dredge were brought down from the winter harbor in Green River, renovated, and moored next to the banks at the settling basins of the filtration plant. The discharges of the pumps were connected by temporary pipe lines to the mixing basins and thus raw water was pumped to the filtration plant.

The water system has a 25 M. G. gallon storage reservoir located in the hills about 5 miles from the City which floats on the pressure system. This reservoir was practically full when the shut down occurred.

The clear well of the filtration plant with 2 M. G. capacity, had a leakage of about 160,000 gallons per day. This leakage and inability to wash the filters until February 4th resulted in turbid water. After February 8th the leakage was stopped and the system was filled with clear water having a residual of 1.5 to 3.0 parts per million in the main system. From February 2nd until February 18th over 4 parts per million of chlorine was placed in the City's water mains. From February 18th to February 21st over 6 parts per million of chlorine was placed in the City's water mains. From February 12th on, the mains were flushed every day. Bacteriological tests as a whole were very satisfactory, though later in February, after the system was cleared up certain samples had to be proven in the completed tests.

During the entire period the city was under Martial Law and a full quota of health representatives were on hand. Unfortunately one after another of the State Health Engineers were taken ill and the field work had to be repeated, thus delaying the final approval of the potability of the water supply for drinking and all purposes until March 1st. Not one known case of typhoid was found in Evansville, and while several persons passed on due to the strain and pneumonia, yet we have no record of any drownings caused by the flood in Evansville.

LESSONS LEARNED

The important facts to be explained in this discussion of the experience at Evansville and other cities for the benefit of the future are:

1. That the cost of the shut down, the work of dewatering, and the temporary pumping together with food, boots, emergency boots, etc., was somewhat in excess of $27,000.
2. That the cost of repairing the leaks where the large volumes of water gained entrances to the station from the outside after the water subsided was less than several thousand dollars.
3. That all pipe holes carried through foundation walls must be caulked, grouted in, or made water tight from the outside as well as the inside.
   a. Caulking holes from the inside in cramped space caused by many pipe lines is an almost impossible work.
   b. Practically all the pipe lines laid in the Evansville plant through the foundation were left ungrouted and the installations were made under field supervision of retained Engineers.
4. That abandoned pipe lines should be sealed water tight if cut off, outside of foundation walls.
5. That sewer lines or drains at water plants subjected to high water influence shall be constructed of cast iron pipe with tested joints.
6. That all toilet rooms, showers, floor drains, connected to sewers shall be equipped with gate valves when the plant is subjected to high water influence.

7. That water plant superintendents and their personnel in times of emergency stress are not infallible against wearing out under the stress of many continuous hours of strained work. These operators in charge should feel free to call upon other departments or outside help to assist them in times of extreme emergency. It is always much more reasonable to ask for all the help one needs, than to lay the water department open to unfavorable comment.
8. That while the pump station and filtration plant are only 65 feet apart, for several days, communications between the two had to be made by boat. Later a runway was built between the two plants. As stated previously, no steam or electric power was available in the filtration plant until the river stage lowered to 50 feet.
9. That safe operating installation of steam lines and electric cables, etc., should not be sacrificed for beautiful interiors. The placing of steam lines and cables in basements, placing auxiliary equipment for turbine driven pumps in pits underneath sometimes works a severe hardship on the water plant operator in periods of leakage and breaks of station mains.
10. That the American Public, using water, does not realize the value of potable public water supplies until the shut down occurs, at that time the absolute needs from the private and industrial consumers clamours forth to the chief executive of the city affected in no concealed terms. It therefore behooves this Association to preach the doctrine to every man in charge of water utility service that he is responsible for those physical structures taken over by him and that such unsealed pipe lines passing through foundation walls, or other defects left by a previous superintendent are his responsibility and must be remedied at once. The importance of delivering potable water at all times, protecting structures and equipment has been the byword of this Association for years, but a more personal program could be inaugurated through the association's offices so that each new city executive is made acquainted with his water utility responsibility to his public.

PROTECTIVE MEASURES PLANNED

The protective measures to be taken at the Evansville water plant for the future are planned as follows:

1. All known places of leakage are to be made as water tight as possible, and doorways are to be made so that they may be water tight by bricking up or other means.
2. Flood protection embankments and walls will be constructed around those water plants subjected to future floods of such size as to form a first line of defense against high water, and that no pipes will be permitted to extend through these walls which cannot be closed off by the installation of valves.
3. All structures of the same plant are to be interconnected by structures so that shower and toilet rooms, offices, laboratories, and a high level refuge for operators may be available in times of flood emergency. Such interconnecting structures permit the installation of electric cables, steam lines, and other auxiliary lines in accessible dry basements or corridors.
4. The coal hopper pit walls will be built above high water so that the boiler room, which is the heart of the plant, is protected from future flooding.
5. Such steam low lift pumps, wash water sump pumps and emergency high water equipment are to be reinstalled and kept in operating condition.
6. Plans for these protective measures have been submitted to the city by the Consulting Engineers, Alvord, Burdick and Howsen which fulfil every detail at an estimated cost of $164,000.

SUMMARY

In closing this frank discussion of the effects of the 1937 flood at Evansville, credit must be given to the superintendent and his operating personnel as they were worn out with the continuous fighting of leakage between the river stages of 48 feet and 52 feet. In a closing comment on the River Front Project the flood waters were 4 feet over the boulevard, relief boats and barges bumped and were moored against the balustrade. Buildings collapsed or were condemned on the city side to the extent of $200,000. Slight

settlement in the roadway, sidewalks, and slope paving have been mud-jacked back at a cost of $4,000. All remaining damage will be repaired at a cost not to exceed $6,000. Evansville was 42 percent inundated. The flood caused the damage estimated at about $8,000,000 to private property and industry and the damage estimated at $1,875,000 to public property.

Many sewers require new lining, several streets require filling in and resurfacing, and many condemned buildings still mar the river front yet Evansville is again presentable with its plaza and balustrade, Sunset Park and water plant extending along the Ohio River bank.

WATER PLANT OPERATION DURING THE 1937 FLOOD AT PADUCAH *

By Lois Sutherland

(*Treasurer, Paducah Water Works, Paducah, Kentucky*)

Like most other cities on the Ohio River, Paducah, western Kentucky's largest city, was visited during the latter part of January and the first half of February, 1937, by the highest and most disastrous flood on record. Until the last survivor goes to his reward, people will still be talking about the deluge which covered seven-eights of the city. More than 32,000 of the 40,000 inhabitants were forced to leave their homes by the onrush of the mighty Ohio. It was literally an onrush—if you had been in a boat in the center of one of the streets, you would have thought that the river had changed its course, and that the main current was flowing through the streets.

Located as Paducah is, at the junction of the Tennessee and Ohio Rivers, and about 40 miles above the Mississippi, it is not at all unusual for the river to reach the flood stage of forty-three feet. Therefore, little attention was paid to the rise of the river until January 18th, when it reached a stage of 44.7 feet. Even then, no one thought that it would equal the flood of 1913 with a record stage of 54.3 feet. On January 21st, the river was at a stage of fifty feet, surpassing the 49.1 feet of 1936, which was the highest since 1913. Even then, people who had been safely above the 1913 stage, did not worry much. But when, within twenty-four hours, the river rose 2.7 feet, the situation became serious and a general exodus began. Saturday, January 23rd, a new peak of 54.6 feet was reached. On that morning, a good citizen of Paducah was much surprised, on arising, to set his bare feet into a pool of water instead of on the dry floor from which he had stepped the night before. On and on came the Ohio, two feet a day, a foot a day, a few inches a day, until finally, on February 2nd, it reached its crest of 60.8 feet, approximately 40 feet above normal stage. All but the extreme west end of the city

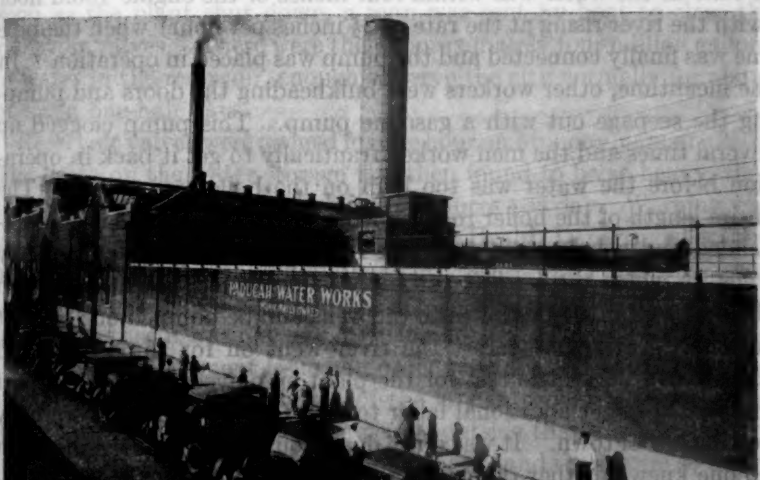
* Presented at the joint meeting of the Southeastern and Kentucky-Tennessee sections, April, 1937.

was covered with water, with a depth of from six to twelve feet in the business section of the city. On February 4th, the waters began to recede, first by inches, then by feet, until on February 21st, the river was back within bounds.

Normally the municipally owned water works, located on First Street, is two hundred feet from the Ohio River, but during the flood, the water plant seemed to be almost in the center of the river. Built in 1884, for fifty-three years Paducah's water plant had furnished water to its citizens without any interruption of service. This record is more remarkable in view of the fact that until the past summer of 1936, when a five million gallon storage reservoir was completed, the plant pumped direct, without any reserve supply of water. Even in 1913, the plant continued to operate. But, at 7:15 o'clock, Sunday evening, January 24th, the record was broken and the plant was closed down for the first time in its history.

All the main buildings or structures of the water works, except the office building and the reservoir, are located within one square block. On the corner is an open, reinforced concrete and brick coagulation basin. Adjacent to the coagulation basin is the filter building which is equipped with six rapid sand filters of a total rated capacity of six million gallons. Beneath the filters is a reinforced concrete clear well with an available storage of three hundred ninety thousand gallons. Adjoining the filter building is the pumping station. The main engine room floor, where the high lift pumps are located, is at an elevation of 54.9 feet while the pump pit floor, where the low lift pumps are located, is at an elevation of 17.5 feet. Connected to the engine room is the boiler room, which has a floor elevation of 53.9 feet. Back of the main buildings are a steel sedimentation tank, a steel standpipe, which is used to wash filters, a meter repair building, a blacksmith shop, store buildings and garage. The yard back of the plant is about four feet higher than the floor elevation of the main buildings. As the river approached flood stage, we had just completed removing two old Holly vertical compound pumps which had not been in use for over ten years. Beneath these pumps were large wells and there was a suction line extending to the river through an old tunnel. Water always stood in these wells on a level with the river. We were preparing to close off this suction line to prevent the water from ever rising in the wells, but the sudden rise in the river made that impossible.

PADUCAH WATER WORKS AT 1937 FLOOD CREST



SAME VIEW, JULY, 1937

FIGHTING AGAINST THE FLOOD

On January 21st, we realized we were going to have a flood equal to or higher than the 1913 stage. This meant that the water plant would be surrounded by water, with no way out except by boat. We were further handicapped by having no telephone service at the plant as this service had not been restored since the sleet storm hit Paducah on January 9th and 10th, seriously damaging the telephone and light and power lines. Enough coal was stored to operate the plant for a month. Food, stoves, cooking utensils, cots and bedding were rushed to the plant, as the employees would have to live there during the flood. Lumber was bought to bulkhead the doors and windows, and a fight against time and the river was on. By the afternoon of January 22nd, it was impossible to drive a truck to the plant, so many supplies had to be taken in by boat. Water was rising rapidly in the wells where the Holly pumps had been installed. Emergency piping was run from one of the low lift pumps to these wells, to pump the water out as the river continued to rise. This was completed barely in time as the water was within four inches of the engine room floor (with the river rising at the rate of 2½ inches per hour) when the pipe line was finally connected and the pump was placed in operation. In the meantime, other workers were bulkheading the doors and pumping the seepage out with a gasoline pump. This pump clogged up several times and the men worked frantically to get it back in operation before the water was too high on the boiler room floor. The entire length of the boiler room in front of the boilers was then bulkheaded and a hole cut through from the boiler room to the Holly wells, to which the low lift turbine was connected, so that water in the boiler room would flow into the wells and be pumped out by that turbine. The fight against the river went on for three days and nights with very little rest for the plant employees. It was almost impossible to get additional labor to help for most people were busy getting out of town. It was quite dangerous working in the plant for no one knew whether the walls would hold against the terrible pressure of the river.

On Sunday, January 24th, water started coming into the plant through the south wall of the boiler room and also came over the higher elevation of the yard back of the plant. All day Sunday, the men worked without stopping, sandbagging and trying to keep the water out of the plant but late Sunday evening, the plant superin-

tendent saw that the fight was hopeless and that they could not continue to operate. If the river had not been rising so rapidly, and if we could have had more time, we could probably have kept it out, but it rose so fast and came in on us from so many directions at once, that it was impossible to keep it out at all points. The men shut down the turbines, cooled the boilers, closed the valve to the distribution system and also the valve to the steel standpipe in order to hold it full of clean water to clean up the plant after the river went down. Records and laboratory supplies were carried up into the filter room. At 7:15 o'clock P.M. the river, at a stage of 57.3 feet, took charge of the plant.

EMERGENCY OPERATIONS

Our new reservoir built last summer, was located about three and one-half miles from the plant. The device to record the water levels in the reservoir had been out of operation since the sleet storm of January 9th, so there had been no way at the plant to tell just how much water was in the reservoir, except by going out there. As soon as the plant shut down, a man was sent by boat to close the reservoir valves. There were then approximately four million gallons of water in the reservoir, enough to serve the city normally for about one and one-half days.

Reservoir valves were opened for one hour on Monday, January 25th. The drain on the water storage was then found to be so heavy, that the time was then limited to fifteen minutes per day. Warning was issued by the Water Department and the Health Department to boil all water used for drinking and cooking. The water was safe when the plant was shut down but with it standing so long there was a possibility that it was not safe. On January 28th, the Red Cross and the Health Department issued an order to the Water Department to shut off all of the flooded area of the city in order to conserve the limited amount of water for the people outside that area. So many faucets had been left open in the flooded area and there were so many leaks that the water was being wasted and with the telephones, lights, power and radio off in the flooded area, there was no way to warn the people not to use the water without first boiling it. By that time most of the people had been evacuated. There was no train service to Paducah and only one highway out of the city open. Drinking water was hauled to the west end of the city from Mayfield and rationed to the people. All wells outside the flooded area were

heavily chlorinated. A temporary office and laboratory was opened up by the Water Department in the high western part of the city.

On January 30, 1937, E. J. Herringer, Jr., Sanitary Engineer of the Public Health Service was placed in charge of the water supply during the emergency.

Arrangements were made by water works officials to obtain the services of factory men of the Dravo-Doyle Company to help in the reconditioning of all of our pumping equipment and also with the Wallace & Tiernan Company for necessary equipment and the service of one of their engineers to assist in sterilizing the plant and distribution system. All necessary chemicals and supplies were ordered and rushed to Paducah to be in readiness to get the water plant back in operation as soon as possible. A new electric deep well pump was ordered to pump the water out of the plant.

When the crest of 60.8 feet was reached on February 2, 1937, water was six feet deep in the engine room, seven feet deep in the boiler room, the pump pit was of course completely filled, and the clear well was contaminated by the river water.

RESTORATION OF SERVICE

On Friday, February 12th, when the river reached a stage of 54.8 feet, work was started in the plant, cleaning out the mud and on Saturday, February 13th, work was started pumping out the turbine pit and reconditioning one of the high service turbines. A slow fire was built in one of the boilers to dry out the brick settings which had been under water. Other men were at work pumping out the pump pit. This work was handicapped by the intermittent light and power service but gasoline pumps were used and the work went on. As soon as the pump pit was pumped out and cleaned, the high service turbine was ready for service and the mechanics started work on the low service turbine. Workers then began pumping out and cleaning the clear well. Our filter plant is old, having been built in 1904, and the clear well was not designed so that it could be cleaned without shutting down the plant. Consequently this is the first time it has ever been pumped out and cleaned.

By Thursday, February 18th, the clear well had been cleaned and all necessary equipment put in service. All filters were back washed and filter beds sterilized with a heavy dosage of chlorine. The settling basin and stand pipe were filled and at 9:15 P.M. Thursday, February 18th, water was turned into the mains. The water was

treated at the plant with a chlorine dosage of 10 parts per million. Men were busy all night opening fire plugs in all parts of the city to flush the mains. By Friday morning, the entire city was supplied with water, but the people were still warned not to use this water for drinking or cooking purposes without boiling. For two days a chlorine residual of three parts per million was maintained at all dead ends and remote points of the system. The chlorine dosage was then reduced to 0.4 part per million and on Tuesday, February 23rd, bacteria examinations were made of the water from all sections of the city. Approximately 100 samples of water were tested and showed no coliform organisms or gas formation. To date, there have been only three cases of typhoid and those cases were caused by working or living in the flooded area.

On Thursday, February 25th, the water was declared absolutely safe for all purposes by Mr. Herringer of the Public Health Service.

We were very fortunate in regard to the damage to our distribution system. We had only one break in a 16-inch main, only three broken fire plugs, a few leaks in service lines and very little damage to meters.

We are proud of the fact that we were able to resume operation of our plant within six days from the time we actually started pumping out the river water, but we were fortunate in having such splendid cooperation from everyone, particularly the U. S. Public Health Service, the State and County Boards of Health, the Works Progress Administration and the Illinois Central Railroad, all of whom gave us every assistance possible.

Discussion by ROBERT SHAPIRO*: Restoration of service at the Paducah plant was a difficult task. The entire water works plant was flooded except for the filters and the high wash-water tank. The pumps were in a pit about 45 feet deep and the clear-well for filtered water was full of flood water. The main floor of the water works itself was under about six feet of water, covering chlorinator, pumps, electric generators, instruments and the various rooms connected with the plant. Reclaiming the plant had to wait for the flood waters to drop down below the level of the pit so that it could be pumped out.

* Bacteriologist, Mt. Prospect Laboratory, Department of Water Supply, New York, N. Y. Mr. Shapiro was one of a group of engineers and laboratory workers sent into the flood area for emergency service. This account is taken from the report he made concerning his various assignments.

The pit was pumped out by two portable pumps, a six and a three inch. As soon as the level was below the first stage, the turbines were taken apart. The steam pumps and turbines on the main floor were taken apart, cleaned, oiled and re-assembled.

The filters had not been submerged, but the clear-well had been flooded. The clear-well was pumped out entirely and heavily chlorinated. Mr. Mitchell, the plant superintendent, had very wisely kept a reserve of a clean filtered water in his wash-water holding tanks, throughout the flood period. For this reason, it simplified the start of operations. Good wash-water could immediately be used to wash the filters. Considerable time and trouble was saved by this foresight. The filtered water going into the clear-well was heavily chlorinated so as to sterilize this compartment. Emergency Wallace & Tiernan chlorinators were set up to feed to the filter, clear-well, and directly into the distribution system. They were capable of feeding about 300 pounds of chlorine a day to an ordinary three to five million gallon a day supply.

Water had to be used for cleaning up the homes and business places and for sanitary purposes. So by radio and newspaper, the townspeople, who had begun the task of cleaning up, were told that water would be avilable for these purposes, but that it was not fit for drinking unless boiled. This precaution was taken, despite a very high residual (about 3.0 p.p.m.) being carried because it was not known to what extent the mains were broken and how much back siphonage had occurred due to open faucets and fixtures. To clean out the distribution system, two crews traveled around and flushed out all dead ends. These were allowed to flush about one hour after they had shown a chlorine residual of at least 1.0 p.p.m. Every single dead end was flushed in this manner at least twice. It was difficult, despite the very high dose being applied, to maintain the residual at the ends of some of the longer lines, but eventually every distribution line was checked.

These high residuals were maintained for about three days after flushing and then cut down to 0.1 to 0.2 p.p.m. As a final check on the Paducah water, bacteriological samples were taken at the ends of each distribution line. These were taken from house taps or from outdoor faucets. A free chlorine test was taken at the same time to be sure that we weren't testing a highly chlorinated dead end. I collected all these samples and made the free chlorine tests myself

because we were very anxious to avoid possible error. It was very important for the morale of the returning inhabitants for us to be able to declare the water supply safe for drinking as soon as possible. The principal samples were all collected by February 24th. All were negative for B. coli in 10 cc. quantities, so that the water was then declared safe for use without boiling.

CAIRO AND THE SUPERFLOOD OF 1937*

By C. M. Roos

(Supt. The Cairo Water Co., Cairo, Illinois)

A spear head shaped strip of land jutting southward to a point at the confluence of the Ohio and Mississippi rivers, with the city of Cairo located on the wide part of the spear head, with the 6500 acre Cairo Industrial District connected therewith to the north, forms the extreme southern tip of Illinois, at about the same latitude as Richmond, Virginia.

The elevation of this combined area is 40 to 46 feet above low water mark, or 310.42 to 316.42 feet above gulf level at Biloxi, Mississippi. This combined area is protected by levees 60 feet above low water mark.

A three million dollar vehicular bridge crosses the Mississippi River at this point, a long railroad bridge crosses the Ohio River, and a two and one-half million dollar vehicular bridge is now being constructed across the Ohio.

Four railroads, a net work of improved highways, a commodious deep harbor teeming with river craft, open year round navigable channel to the sea, and the unique geographical location, are a few of many reasons why a city is located at this spot and explain why a city of importance will always exist there. The existence and adequate protection of the city are well justified.

THE CITY PROTECTED

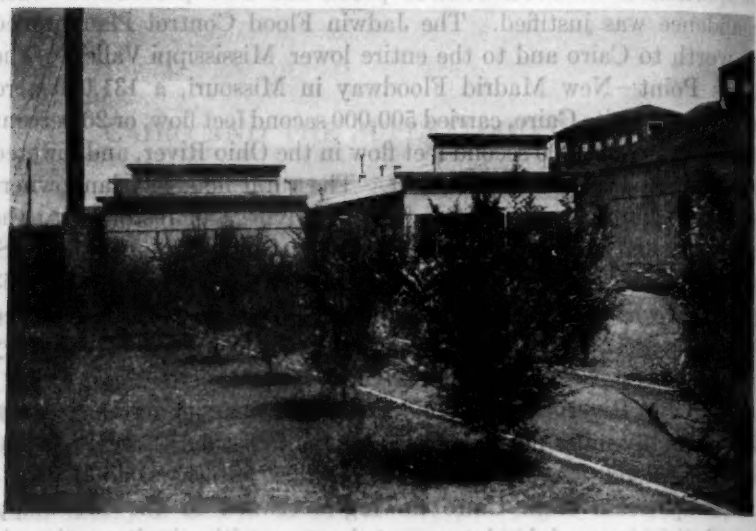
The eyes of the world were focused on this spot during the 1937 flood as news went out directing attention to Cairo's apparent exposed position. The facts do not justify many of the sensational reports as to the danger of inundation. The highest flood of record at Cairo was in 1927 when the crest was 56.4 feet. A 62 to 63 feet crest was predicted for the 1937 flood. The crest was 59.62 feet. The city's calm confidence that it would escape inundation amazed newspaper reporters who were not familiar with all of the facts,

*Presented at the Buffalo convention, June 9, 1937.

inexperienced in flood control provisions and procedure. Such confidence was justified. The Jadwin Flood Control Plan proved its worth to Cairo and to the entire lower Mississippi Valley. The Birds Point—New Madrid Floodway in Missouri, a 131,000 acre spillway opposite Cairo, carried 500,000 second feet flow, or 26 percent of the total 1,900,000 second feet flow in the Ohio River, and lowered the crest at Cairo at least 3 feet. The rural floodway landowners were adequately paid in cash for the privilege of restoring to the rivers this natural overflow area. With the cooperation of the U. S. Army Engineers Cairo's levees were raised 3 feet when the 1937 63 foot crest was predicted as a possibility. Cairo has not been flooded for nearly a century. The city can know with considerable accuracy probable crests several days in advance.

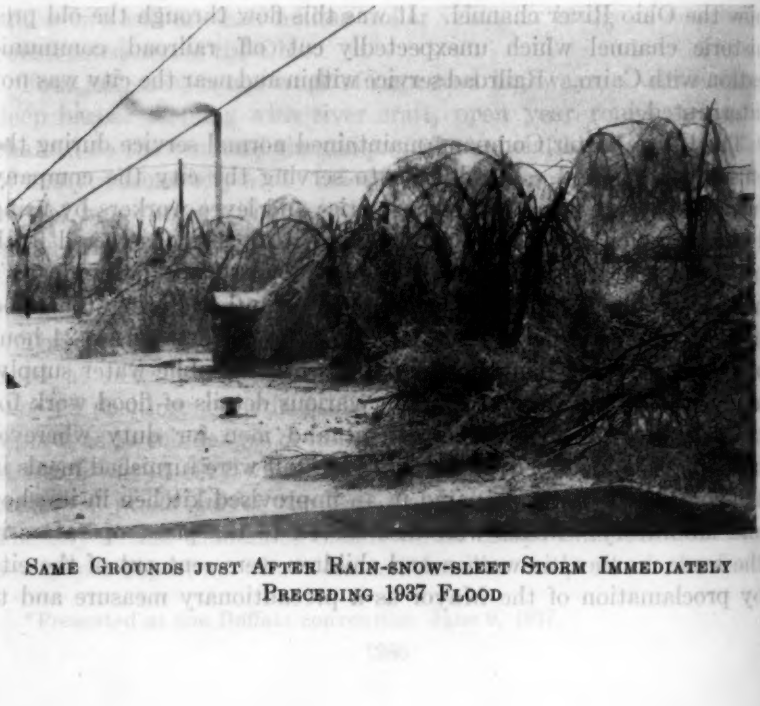
The Ohio River sought its old prehistoric channel across southern Illinois many miles north of Cairo for the first time of record during the 1937 flood. A 71,000 second feet flow left the Ohio River 75 miles upstream from Cairo flowing westward to the Mississippi inundating many inland towns and communities in its path. At some period the Ohio River abandoned this old channel, cutting through a section of much higher elevation, joined the Cumberland and Tennessee rivers, flowing with them to the Mississippi which is now the Ohio River channel. It was this flow through the old prehistoric channel which unexpectedly cut off railroad communication with Cairo. Railroad service within and near the city was not interrupted.

The Cairo Water Company maintained normal service during the entire flood period. In addition to serving the city the company furnished water to nearby communities and levee workers by using 160 five gallon glass containers, transporting them back and forth by trucks, boats and rail. Construction work on the company's new filter plant continued without interruption during the flood period. The water office and laboratory were operated on 24 hour schedules, making hourly examinations of the public water supply, analyzing ground waters, handling various details of flood work for the city, and furnishing equipment and men for duty wherever needed. The members of the enlarged staff were furnished meals in the company's office, prepared in an improvised kitchen in its shop and laboratory. Meals were also served to the plant operators in the same manner, as women and children were sent out of the city by proclamation of the Mayor as a precautionary measure and to



GROUNDS ABOUT CAIRO PUMPING STATION—1936

River levee at extreme left about 15 feet above station grounds elevation



SAME GROUNDS JUST AFTER RAIN-SNOW-SLEET STORM IMMEDIATELY PRECEDING 1937 FLOOD

Top of Levee when 1937 Flood Was at Its Height

Pumping station at right. Note sand bag levee extension—about three feet high

Close-up View of Levee Opposite Pumping Station at Flood Crest

leave the men free from the responsibility of providing for their families.

EMERGENCY MEASURES

As a precautionary measure the Water Company provided facilities to furnish safe drinking water in the event the city should be inundated. A 200,000 gallon elevated tank was filled and gated off, with a riser pipe lashed against one of the steel tower columns extending above flood level for use in delivering water in bottles and milk cans. Two deep artesian wells were piped by the company to the second floors of two hotels. Hand operated pumps were provided as the artesian flow would not rise to this elevation. Motor driven pumps would have been useless as inundation of the city would have cut off electric power service. Gasoline driven pumps were also available if needed for this temporary service.

Coast guard boats, scores of them, were sent to Cairo by rail and water. Six companies of National Guards were quartered at the Cairo armory and did patrol duty in the city and in nearby towns. Army and C.C. Camp trucks formed caravans transporting men and supplies to and from the city and nearby communities. W.P.A. men and C.C. Camp boys were sent to Cairo in large numbers to assist in the work. The U. S. Engineers maintained headquarters in the city, occupying a five story building with a staff of 250 people serving a wide territory in emergency flood control work.

"SAND BOILS"

The "sand boil" phenomenon afforded an interesting subject for sensational newspaper reports. Many reporters heard of and saw so called sand boils for the first time during the recent flood. There is no mystery about sand boils. These boils are ordinary springs which flow only during periods when the normal underground flow to and with the rivers is restricted. Contrary to the age long belief of many, including natives of levied areas, sand spring water does not come from the rivers. To establish this fact as a matter of record the management of The Cairo Water Company has made an exhaustive study of the subject, including analyses of hundreds of samples of ground waters, sand, soils, studying geological formations, rainfall, topography, rates of flow, direction of flow, and pressures and elevations of ground waters at different depths. The report of these studies is very interesting. Wherever levees protect sur-

rounding areas sand springs are invariably found during periods of high water.

Rainfall is absorbed in the Ozark uplift within 25 miles north of Cairo where old Silurian and Devonian rocks shattered by acid action ages ago rise to an elevation of 300 to 400 feet above the city's street grade. These same rock formations are found 700 feet below the surface at Cairo, or about 400 feet below sea level. This means a precipitous dip of 1000 feet in a distance of 25 miles, forming a half funnel shaped condition at the Cairo point, with the two rivers representing the sides of the funnel. As the funnel sides rise with the rise of the rivers restricting the normal underground flow through both the sides and the spout, these ground waters rise seeking the river levels.

Alternating sand and impervious clay strata in the alluvial deposits for a depth of 700 feet at Cairo separate ground water flows and confine them to well defined water bearing veins. The water bearing sand at the 70 to 100 foot depth at Cairo is coarse, deposited when the bottom of the rivers was there and this sand will not rise to the surface even when freely released through test wells. At a depth of 15 to 25 feet, however, is very fine quartz sand which flows freely during flood periods when water from this stratum is released through natural spring openings or abandoned wells. Only four so called chronic sand boil areas exist in Cairo which always flow during flood periods. These areas are in undeveloped sections of the city. Water from the sand boil stratum is at low head rising only about four feet above street level when rivers are at crest stage. Temporary control is provided by surrounding the sand boil with a wall of sand bags, preventing the sand from rising to this elevation and diminishing the flow of water. The flow of water is not objectionable as it is quite limited. Damage results from sand boils only when cavities are permitted to form where sand has escaped and the clay overburden settles. If such flows find an opening in a defective sewer, as it does occasionally, sand escapes rapidly because of the lower head and sewer collapse follows. Effective treatment is simply to gate off the affected sewer section, thus stopping the flow of water and sand through it. This condition is not peculiar to Cairo, but is found in all cities where river stages rise above sewer levels requiring the use of drainage pumps. The only danger of sand boils weakening levee protection is if cavities are permitted to form under a levee causing the surface to settle, thus lowering its height. Fortunately Cairo

has not had any such condition as sand boil areas are not near the levees.

Permanent treatment of sand boil areas does not present difficult engineering problems nor does it involve great expense. As a result of studies and experiments made recently undoubtedly all sand boil areas in Cairo will soon be treated to prevent recurrence of this trouble. Such permanent treatment consists of filling underground cavities with cement grout forcing it down by compressed air at from 50 to 75 pounds pressure. Following the grouting treatment a blanket of clay is placed over the affected area to raise the surface elevation to a point above which the ground water will not rise during floods.

The sand from the sand boil stratum is in relatively thin veins in most places. It was deposited when the area was covered over a long period in the form of a lake or arm of the river with a current of just the proper velocity to uniformly drop suspended matter of a certain size, carrying finer materials in suspension down stream, having theretofore dropped the heavier materials in or near the channel of the stream. This almost pure quartz sand boil sand has a porosity of from 39 to 47 percent of its volume, a density of 1.41 including voids and 2.47 excluding voids, and 50 percent of some samples pass through a 325 mesh sieve. The water from this stratum during flood periods and at other times has an alkalinity twenty times that of river water, with temperatures, mineral content and other characteristics so unlike those of the river water that no room is left for doubt as to its origin.

These studies of ground waters suggested the advisibility of cutting off the flow from the source by driving long interlocking sheet steel piling across the narrow neck between the rivers immediately north of Cairo. Objections to this plan are similar to those made by some engineers against the construction of the Florida ship canal. The canal might cut off the ground water flow to the peninsula and make Florida an arid waste. If piling could cut off ground water flows toward Cairo, which is improbable, there would be a possibility of damage by removing the ground water counterpressure against the weight or head of river water on the soil under Cairo, during high stages.

Underground sand strata leading toward and under the rivers operate similar to a swinging check valve, opening when the flow into the river is from the land side, and closing by precipitated sedi-

ment filling the sand voids as soon as the turbid steam rises much above such openings. Any operator of a mechanical filter plant who has tried to put turbid water through a filter bed can understand the soundness of this theory.

An interesting observation has been made of a deep well in Cairo which appears to be affected by tidal action. A report on this which is awaited with interest by authorities will be made later. A later report will also include results of experiments in gaging elevations of ground water and character of soil formations by using an electrical instrument to determine earth resistivity.

FUTURE POLICIES

Studies of flood problems at Cairo have lead to some rather definite conclusions, including the following:

1. Ground waters and sand boils present no difficult problems which cannot be treated effectively and at reasonable expense.
2. Ground waters do not flow from the rivers.
3. Sand boils do not endanger a community during flood periods unless they are near a levee and cavities are permitted to form under the levee causing it to settle.
4. No difficulties in designing foundations for heavy structures need be experienced in Cairo if proper practice is followed.
5. Future flood control plans should include restoring to the rivers an adequate part of their natural floodways, thus lowering flood crests. The centers of population should have adequate levee protection.
6. Some types of lowlands are more valuable for agricultural purposes without levees than with them.
7. Flood control by reforestation has some merit, but it has been overemphasized. The major flood of 1844 occurred when virgin forests were everywhere.
8. Likewise flood control by means of reservoirs at the headwaters has some merit, but the cost is high and results limited.

WATER WORKS LESSONS FROM THE 1937 OHIO RIVER FLOOD*

By L. R. Howson

(Alvord, Burdick and Howson, Chicago, Illinois)

This discussion will deal with the general aspects of the 1937 Ohio river flood as affecting water works operations.

An attempt will be made to summarize the experiences related in the several previous papers and to indicate some of the fundamental considerations which will assist in minimizing the effect of recurring floods.

The prior papers cover the entire 1,000 mile reach of the Ohio from Pittsburgh to Cairo. In this region approximately 1,500,000 people living in 100 communities were without water service for periods varying from a few days to several weeks. In some of these cities only small areas were under water but in others, including Huntington, Ironton, Portsmouth, Louisville, New Albany, and Paducah, from 50 to 90 percent of the occupied part of the cities was submerged under water depths varying from 5 to 30 ft. This flood made it possible to see and appreciate the indispensability of water service which is usually left only to sheer imagination. The oft repeated phrase, "Water, water everywhere and not a drop to drink" was a literal expression of the conditions which faced a million and a half people during the 1937 Ohio river flood.

MAGNITUDE OF FLOOD

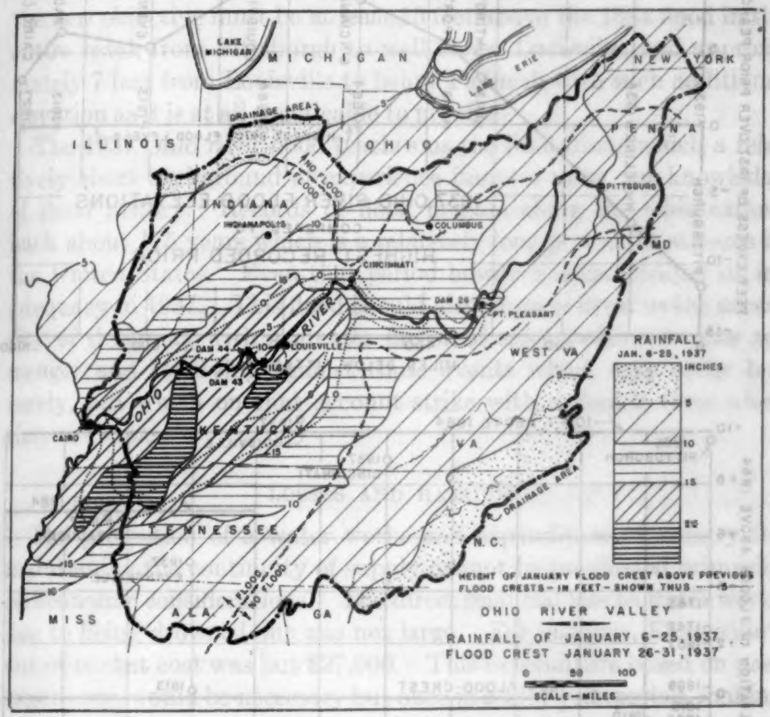
The 1937 flood water elevations exceeded all others of record in the 800 mile reach from above Huntington to Cairo and in that reach only Ashland, Ky., and Cairo, Ill., of the larger water works continued to function. When it is recalled that Cairo occupies a wedge of low lying land whose elevation is some 20 ft. below flood level, it is indeed more than a coincidence that water service was maintained there. Cairo, like Noah, prepared for a flood.

The magnitude of the flood can be visualized by the statement

*Presented at the Buffalo convention, June 9, 1937.

that the flow of approximately 2 million cubic feet per second in the lower reaches was equal to a day's use of New York City each minute, or a four years' supply for New York went downstream each twenty-four hours.

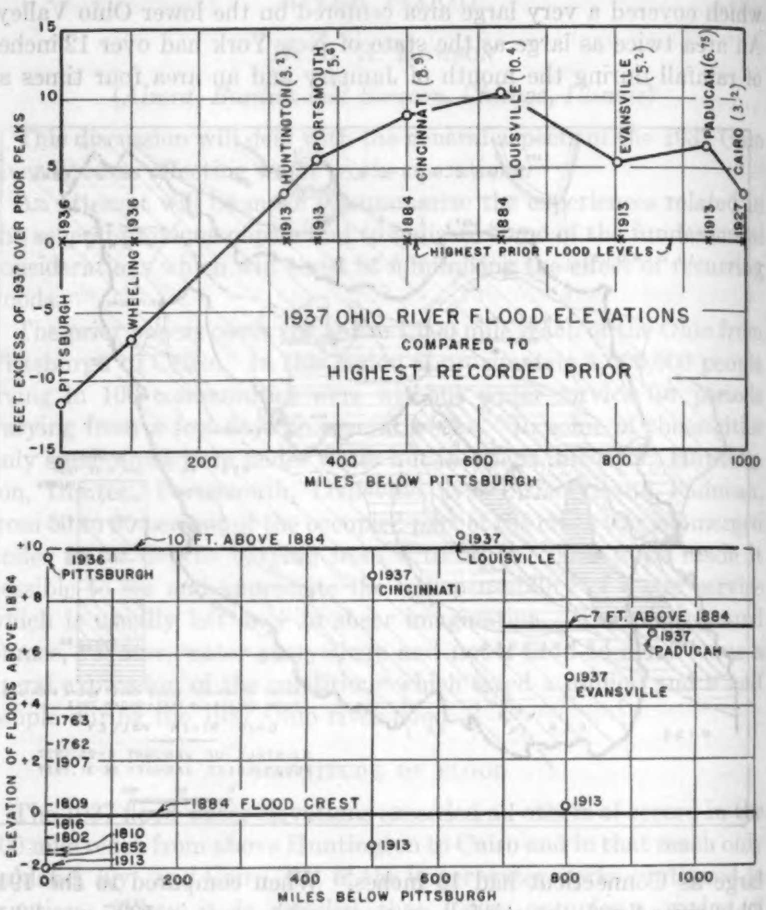
The flood was caused primarily by an exceedingly heavy rainfall which covered a very large area centered on the lower Ohio Valley. An area twice as large as the state of New York had over 12 inches of rainfall during the month of January and an area four times as



large as Connecticut had 16 inches. When compared to the 1913 Ohio river flood, the rainfall on comparable areas in 1937 was 60 to 70 percent greater. Had the 1937 rainfall been centered more to the northeast it is probable that the Upper Ohio river cities at least would have experienced still higher flood crests. As a result of the heavy rainfall all Ohio river tributaries were above flood levels and in many of the more important, including the Kentucky, Cumberland and Tennessee, flood flows exceeding any previously recorded, were ex-

perienced. The Ohio was in flood from Pittsburgh to Cairo with its worst concentration at Louisville where the flood crest exceeded all previous records by $10\frac{1}{2}$ feet.

The question naturally arises why were not the water plants built with a liberal freeboard above flood height. The answer to that



question is that most of them were so built as evidenced by their records of service through the 1884 and 1913 floods but with the 1937 flood crest as much as $10\frac{1}{2}$ feet above anything previously recorded during the 200 year occupancy of the valley by white men, the real question is what constitutes a reasonable freeboard?

Practically all of the water works in the more important cities along the Ohio were safe against any flood elevation previously recorded. The 1884 flood was the greatest in over one hundred years for practically the entire length of the Ohio. This 1884 flood, having occurred before most of the major water works were constructed, was taken as the base line in protecting the plants against future floods. The 1937 experience from Huntington downstream and the 1936 experience from Huntington to Pittsburgh, show that this was not a safe basis for design. Certainly with the data now available the new objective must be at least 10 feet above the 1884 flood in the entire reach from Pittsburgh to well below Louisville, and approximately 7 feet from Louisville to below Paducah with such additional elevation as it is at all practicable to provide.

The 1937 Ohio river flood teaches us the limitations which a relatively short background of experience imposes upon our knowledge of flood history. Records of flood heights along the Ohio extend back about 175 years which is a relatively long period for streams in the United States. Even that period however demonstrated its inadequacy in 1937. This flood should also impress upon us the necessity of designing with a greater factor of safety where records are meager and fortifying against those events which may occur but rarely, but which on that account strike with a double force when they do come.

LOSSES AND HAZARDS

The protection of a water works and expenditures necessary for maintaining the continuity of supply cannot be predicated primarily on economic considerations. The direct financial loss to water works due to being drowned out was not large. For instance, Evansville's out of pocket cost was but $27,000. This expenditure based on past experience, would be necessary but once in a fifty year period, making an annual cost of $540.00.

The indirect losses due to the failure of water service at Evansville were very much greater as many of the larger industries were above flood water and their operations were suspended only on account of lack of an adequate water supply. The resulting loss in wages and profits is therefore chargeable to the failure of the water supply.

In most cities the water works must be protected and its continuous operation assured. Economic considerations should then be followed in selecting the best means of accomplishing the desired result.

No one can express in dollars the hazard to health which results from empty mains and back-siphoning of fixtures even though, due to the vigilance and educational work done by those in charge of the public health during the flood, there was an amazing lack of water borne disease following the interruption of water service in the Ohio Valley.

Following closely upon the health hazard is the importance of maintaining pressure in the mains for the supply of fire protection. A great many serious fires developed, the most serious, being the $2,000,000 Standard Oil fire at Cincinnati.

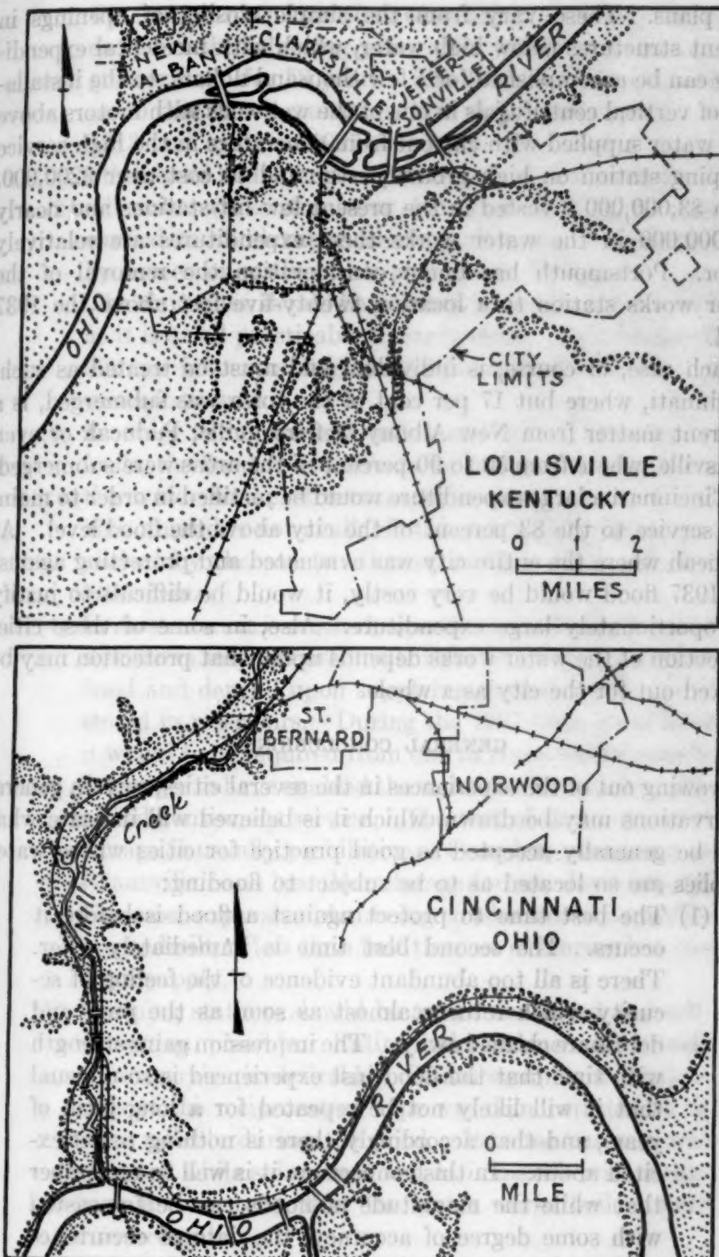
WHAT IS TO BE DONE ABOUT IT?

The question now confronting water departments in the Ohio valley is "what should be done?" Obviously no efforts of the departments can avert repetitions of the 1937 rainfall or of the flood which it produced. The remedy must lie in protecting the water works structures themselves or including their protection in a comprehensive plan for the protection of the city.

Most of the cities affected are giving serious consideration to the most practicable means of guaranteeing the continuity of water supply during any subsequent recurrence of flood conditions. At Evansville an investigation and report has already been made. The plan worked out there consists of filling and raising the level of an area sufficient to accommodate double the capacity of the present water works. In general, this grading and wall enclosure is designed to keep flood water approximately 100 ft. distant from buildings and thus minimize flotation and pressure on the walls. Protection will be provided for a flood elevation 6 feet above that recorded in 1937. The estimated cost of this improvement is but $164,000.

At Cincinnati, consideration is being given to the installation of a vertical electric driven pump with the motor located well above any probable flood elevation. This plan differs from most solutions which, due to the fact that in general electric service was cut off either coincident with, or in advance of, water service, have adopted some independent source of energy such as diesel or gasoline engine or steam. Mr. Hibbs also suggests the enlargement of Cincinnati's storage from 140 million gallons to 500 million gallons, something over a week's supply. These improvements will probably require an expenditure of $3,000,000 to $5,000,000.

At Louisville, there is now in progress a review of several alterna-



SUBMERGED AREAS, CINCINNATI AND LOUISVILLE, 1937 FLOOD

tive plans. These vary from the simple closing of openings in present structures below high water, which with incidental expenditures can be accomplished for a few thousand dollars, to the installation of vertical centrifugals in one of the wet wells with motors above high water supplied with current from generators in the high service pumping station on high ground, estimated to cost over $200,000. With $3,000,000 invested in the present low lift stations and nearly $30,000,000 in the water works these expenditures are relatively minor. Portsmouth has under consideration the removal of the water works station to a location twenty-five feet above the 1937 flood.

Each case, of course, is individual and must be treated as such. Cincinnati, where but 17 per cent of the town was submerged, is a different matter from New Albany, Jeffersonville, Paducah or even Louisville, where from 50 to 90 percent of the areas were submerged. At Cincinnati a large expenditure would be justified in order to maintain service to the 83 percent of the city above the flood level. At Paducah where the entire city was evacuated and protecting against the 1937 flood would be very costly, it would be difficult to justify a proportionately large expenditure. Also, in some of these cities protection of the water works depends upon what protection may be worked out for the city as a whole.

GENERAL CONCLUSIONS

Growing out of the experiences in the several cities, certain general observations may be drawn, which it is believed will indicate what may be generally accepted as good practice for cities whose water supplies are so located as to be subject to flooding:

(1) The best time to protect against a flood is before it occurs. The second best time is immediately after. There is all too abundant evidence of the feeling of security which returns almost as soon as the mud and debris are cleaned away. The impression gains strength with time that the flood just experienced is so unusual that it will likely not be repeated for a long term of years, and that accordingly there is nothing to get excited about. In this connection, it is well to remember that while the magnitude of floods can be forecasted with some degree of accuracy, the date of occurrence cannot be even guessed. The highest flood of record at

Cincinnati up to that time occurred in 1883 only to be exceeded the following year, after which there was no greater flood for 53 years. The highest flood at Cairo up to that time occurred in 1912 only to be exceeded in 1913 and again in 1927 and 1937. Pittsburgh on the other hand had not exceeded its peak of 1763 until 1936.

(2) All water works structures should either be themselves carried to an elevation above high water or protected by levees or walls which accomplish the same result. The elevations should be as much above previous floods as it is at all practicable to carry them. It is better to climb a few extra steps for 50 years than to be out of water for a week.

(3) In order to minimize flotation and relieve pressure on walls, the flood waters should be kept as far away from the water works structures as is practicable. When high ground is not available this can usually be accomplished by the construction of suitable dikes and embankments.

(4) In most cases it is much cheaper to make the water works structures safe against floods than to let the structures flood and depend upon supplying the town with water stored in reservoirs. During the 1937 Ohio river flood it would have required from one to three weeks' supply in storage to have enabled the water works to have maintained continuous service. The cost of that volume of storage is usually prohibitive. Complete protection at Evansville costs less than storage for one day's supply. The most expensive plan being considered at Louisville can be built at less than half the cost of storing but one day's supply.

(5) Pumping stations should be as self-contained and self-reliant as possible. Entire independence of outside power service is desirable. Steam equipment particularly of the reciprocating type was demonstrated to be most reliable during the flood. In some cases it was operated while submerged and at Louisville with steam from a river boat after the water works boilers were drowned out.

Electric utility generating plants on account of the ne-

cessity for large volume of condensing water, are ordinarily located on river banks subject to flooding, and in the 1937 flood were out of service even to a greater extent than the water plants. Electric power for pumping is exposed to the dual hazard of generating station failure and transmission line outage due to flood water damaging towers, conduits, and pole lines.

Steam plants and pumps can be put back into service much more quickly. Many electric plants still have generators out of service due to the flood four months ago.

(6) If there must be doorways or other openings below high water elevation, provide each such opening with a hinged, always available, bulkhead door which can be swung into position and effect a tight closure quickly. A removable bulkhead in storage is as useless as a spare tire at home in the garage.

(7) It should go without saying that the designing of all water works structures, subject to the influence of floods, must be investigated with respect to flotation and upward pressure. If existing structures are to be raised to protect against higher floods their design should also be carefully checked. The porosity and water transmission capacity of the soil on which the structures are built largely affect the requirements. At Ashland, Ky., the wash water tank, weighing when full approximately half a million pounds, was set on top of the 60 foot depth low lift pump pit to counteract flotation. The Ashland plant is equipped with a hinged steel bulkhead door from the chemical unloading platform which was closed during the flood and which was one of the features instrumental in keeping this plant in service.

(8) Every water works system subjected to flood hazard should have an independent electric generating system adequate for operation of auxiliary equipment, as well as furnishing lights.

(10) All valves around the plant should be so located and their location so tied in that they can be found and operated under any conditions of flooding likely to occur. Memory fails when landmarks are submerged. There

should be a map with all valves referenced to buildings, and other points always above high water.

(11) All openings made for pipes passing through walls of structures below maximum high water level must be carefully and completely closed. At least one large plant could have maintained uninterrupted service and others could have continued service for a longer period except for improperly filled pipe openings. All sewers, drains or other pipes passing through dikes or levees should be provided with valves which can be operated during flood stages.

Ingenuity, resourcefulness and determination paid dividends in the flood as in any other emergency. The speed and efficiency with which water service, the most vital of all urban life requirements, was reestablished is a tribute to the water works profession which can only be excelled by its prompt action in devising practical, economically sound measures to avert future recurrences.

SANITATION CONDITIONS IN THE FLOOD AREAS*

By J. K. Hoskins

(Senior Sanitary Engineer)

(U. S. Public Health Service, Cincinnati, Ohio)

The State of Kentucky has over 600 miles of shoreline along the Ohio and Mississippi Rivers and all of this border was affected by high water. Not only the Ohio River low lands, but much of the areas along the tributaries in the central and western parts of the state were flooded as well. The Kentucky River was out of its banks beyond Frankfort and Frankfort was seriously damaged. Floods in the Green, the Cumberland and the Tennessee Rivers extended almost to the Tennessee State border.

SOME EFFECTS OF THE FLOOD

The effects of such an extensive inundation were, of course, widespread. The interruption of communication by railways in Kentucky was almost complete. All of the highways, with few exceptions, were impassable except through the extreme southern part of the state, so that it was not possible to get from one part of the flooded area to another. Public water supplies were put out of service; gas supplies for furnishing heat and fuel were somewhat less affected; electric power generally failed and wire communication service was seriously crippled. In most of the cities and towns that were flooded or partially affected, heating systems of most of the public buildings were out. Particularly in Louisville, where some parts of the business section were not under water entirely, the basements were flooded. Throughout the state over thirty public water supplies were put out of commission, some of them for longer and some for shorter periods.

The most far reaching and acute effect was, of course, the displacement of the human population. In many instances the greater part of the towns and cities was inundated and practically all the people forced back into the high land—back sometimes as far as

* Presented at the Indiana Section Meeting, March, 1937.

Tennessee and in some instances as far as Georgia. In Louisville alone, with a population of over 300,000 in 1930, it was estimated that about two-thirds of the people were out of their homes during flood time. As can be imagined, this sudden movement created an intensive problem in refugee camp and concentration center sanitation. Not only the cities were affected but the rural districts as well, because, of course, large rural areas were flooded. I believe that these rural folk suffered even more than the people in the cities because in general they had to rely largely upon their own resources in getting out and in finding shelter and food.

PROVISION OF EMERGENCY SANITATION MEASURES

As soon as the serious proportions of the flood were realized the U. S. Public Health Service undertook to assist the State Departments of Health by supplying them with additional sanitary engineering and medical service. In the state of Kentucky forty-one trained sanitary engineers were brought in from the Public Health Service and from outside states, some from as far east as Massachusetts and North Carolina, as far south as Georgia and as far north as Wisconsin. We endeavored to place in each flooded town an experienced sanitary engineer and to supply him with one or more sanitary inspectors called in from the dry counties in Kentucky. Kentucky has organized county health units throughout the greater part of the state. (These units consist of trained public health personnel and include as a minimum a doctor, a nurse and a sanitary inspector.) As soon as the seriousness of the flood became apparent, the State Health Commissioner, Dr. A. T. McCormack, drew most of these county units into the inundated areas so that as soon as the engineer arrived at his destination, he co-operated with the local or county health officer and was supplied with a group of inspectors trained in sanitation procedures.

Because of the almost total lack of communication about all the central organization could do at Louisville was to rely upon the initiative and good engineering sense of the men assigned to the various flooded areas. It should be said right here that every one of them did use good judgment and high tribute is paid to each one who served in that emergency. They did a good job. The only instructions we were able to give them were by telephone or telegraph and were of a general nature. They were asked to give first consideration to the sanitation of the public and private water supplies

in their areas, next the milk supply, third, sanitary methods of excreta disposal and then other sanitary problems including the disposal of dead animals. The headquarters office, it was felt, could be of greatest service in assigning details of procedure to the men in the field and devoting its attention to clearing difficulties as they arose—and there were certainly lots of them—some of which could, perhaps, have been avoided and a great many more that could not have been.

The State Board of Health organization was itself, it might be explained, seriously handicapped. The offices and laboratories were flooded and had to be abandoned. Many of the records were altogether inaccessible. Headquarters were established in one of the hotels, but this hotel, as well as most of the others in the city, was without light, heat or water for a period of three weeks or more. The difficulties of functioning under such conditions can well be imagined.

COLLABORATION WITH OTHER GOVERNMENTAL AGENCIES

The Works Progress Administration in the state of Kentucky was of inestimable value in expediting sanitary measures throughout the inundated area. This agency in Kentucky consists of a central, state headquarters body with a district director, and organization in each of the seven districts into which the state is divided. Under each district are the individual county and local supervisors. There is then a complete, skeleton organization covering the entire state for the employent of labor and obtaining necessary materials and supplies. This entire W.P.A. organization was, by executive order, made available for emergency work resulting from the flood with all restrictions removed to expedite and facilitate operations for the protection of life and health of flood sufferers. Wherever a public health need was indicated—and the Public Health Service was the agency designated to determine what were public health needs—the W.P.A. had instructions to undertake the necessary remedial measures without question. This arrangement provided a completely organized, operating body for performing emergency labor promptly and for supplying materials and equipment necessary in the sanitation of the entire flooded area—both urban and rural. The entire W.P.A. organization deserves great credit for the efficient manner in which these obligations were undertaken and carried out.

We stationed with each of the W.P.A. District Directors, a sani-

tary engineer whose duties were to expedite requisitions for labor and supplies from the field engineers stationed in each of the inundated towns or flooded areas, and to resolve difficulties arising between the field health service agencies and county or local W.P.A. authorities. These district sanitary engineers had ample opportunities for exercise of their tact and persuasive powers and they rendered a most valuable service in advising the W.P.A. district directors about procurement of necessary materials for sanitation purposes. The field engineer made up the requisitions for the labor, materials and supplies that he needed in any particular town or area, and transmitted them to either the W.P.A. local supervisor or district director. It was then the function of the W.P.A. organization to provide these needs and perform the sanitary work indicated. In no other way could we have functioned so completely and quickly. The entire flooded area was covered in a minimum of time.

Where W.P.A. labor was insufficient or not promptly organized, the C.C.C. Camps also assisted most effectively in the sanitation of flooded areas. These groups were self contained in that they required no outside provision for food or housing and were well disciplined. They were used only to supplement and never to replace or displace W.P.A. labor. They functioned best in suburban or rural areas or in the smaller communities.

The U. S. Army was also called upon in specific instances and assisted for the most part in the work of policing and guarding quarantined or closed areas made necessary for the protection of property and prevention of looting. The Army also exerted a retarding effect upon the movement of people to their homes before flood waters had receded and clean-up activities had been undertaken. The Army also brought into Louisville a complete field hospital unit which rendered medical and hospital care to a great many of the sick that were otherwise unable to receive attention in the city hospitals because of flood conditions.

SOME EMERGENCY SANITATION PROBLEMS

The sanitation of refugee centers constituted one of the most urgent and extensive problems. The sudden movement of such large numbers of people from their homes without previous provision of any kind for their placement created intense situations requiring urgent sanitary measures. Excreta disposal was one of the immediate necessities. We found it necessary to dig latrines at many

of the concentration centers, particularly where sewers were not available. In some places, temporary structures were built over sewer manholes. It was soon discovered that telephone or cable manholes were not suited for such purposes. Can systems were established in many instances.

Generally the modern school buildings were found to be the most satisfactory centers in which to house refugees, because they were equipped with well lighted rooms, kitchens and other essentials, including heat. Frequently, however, the toilet facilities were found to be inadequate. The rooms were generally well adapted to the distribution of the people as they came in. The Army medical unit was also located in one of the high school buildings in Louisville. It was able to function in that location within a few hours of its arrival in the city because with the housing facilities provided, all that was left to do was for them to organize their medical equipment and start to work.

A general problem, both for the refugee centers and for the general population, was the provision of safe drinking water supplies where the public supply was out of commission, as was the case in most towns. Efforts were always made to provide chlorinated water whether it was imported in tank cars or trucks or milk cans. Men were stationed on the highways where these tank cars came through with instructions to chlorinate each container before it was allowed to proceed. Hypochlorite of lime (HTH, Perchloron, etc.) was generally used for this purpose, the measured dosage depending upon the estimated size of the container. Splashing and churning of the contents during the last part of the journey before it was made available for use was relied upon to effect the mixture of disinfectant and water.

A further problem in refugee centers was the control of crowding and proper provision for prevention of spread of contagious diseases resulting from too close contact. There were also some difficulties in providing heat. In some centers also we had the delousing problem to take care of.

Throughout the inundated areas, the sanitary disposal of excreta was an important consideration. With no water supply, the water carriage system of domestic waste removal became inoperative. Problems of this nature became particularly acute not only in homes but particularly in refugee centers, hotels and public buildings. In these latter, only two courses were open, either to close the regular

toilet facilities and depend upon latrines or can systems, or else provide flushing water carried in by W.P.A. labor. In some cases continuous flushing was effected by this means.

Proper disposal of garbage from refugee centers, restaurants and hotels constituted another problem. This waste material accumulated rapidly and could not be removed because transport equipment was flooded or disposal grounds inaccessible. New, and frequently, temporary dumps had to be provided, not only for the normal accumulations but also for the great quantities of condemned foods and perishable material being removed from the flooded sections. As an example, a dump was acquired for the disposal of thousands of tons of destroyed food stuffs, in an abandoned gravel pit located along a railroad track. Car loads were hauled out and unloaded by W.P.A. labor, after arrangements had been made with the supposed owner of the property. Later it was discovered that the supposed owner was only the lessee and this particular garbage disposal problem is not yet completely solved. This experience indicates only one of the numberless unforeseen difficulties that arise in an amergency of this kind.

Another extensive problem we had to handle in Kentucky was the disposal of dead animals. It was not possible to keep accurate records of the number of farm animals and stock that perished, but enormous numbers of horses, cattle, sheep and poultry were drowned in the rural districts. In one county over 7,000 cattle, horses and mules were buried, another task that fell to the lot of W.P.A. Trenches were dug in many cases with steam shovels or other power diggers and the carcasses covered with a minimum of 3½ feet of earth. Whole dairy herds caught in the water were disposed of in this way.

PUBLIC WATER SUPPLIES

There were some thirty public water supplies in Kentucky that were affected. Some of them were seriously damaged though most of them could be restored quite promptly as the water went down. One of the most common causes of interruption of service was the general failure of outside power. Many of the smaller plants in Kentucky are operated by electric current from the power nets supplied with current from quite distant sources. Failure in any part of such a generation or transmission system was responsible for closing quite a few water supply systems. Pumping equipment

was flooded in nearly every water plant along the river and a good deal of damage was done to electric motors and electrical equipment in these works. A good many of the filtration plants proper are located above high water and were not affected. This is true of the Louisville, Newport, Ashland and Paducah filters. All, with the exception of Ashland, were closed, because the pumping equipment was flooded. No extensive damage was done to disinfection equipment and these devices were able to go into operation soon after the water receded. Wallace & Tiernan, the company supplying most of the chlorinators at Kentucky plants, had emergency chlorinators available and an emergency truck equipped with spare parts on call to go to practically any plant as soon as the water was out. Little delay was experienced from this source.

Water distribution systems were not damaged to any great extent. There were comparatively few breaks on large mains. The greatest damage was done, probably, to house services and meters, where houses were moved or washed away. It was quite difficult in many instances to shut off these connections promptly and infiltration of flood water into the mains continued until the properties were de-watered.

Relation of the experiences in operating the water works systems during this emergency would be a history in itself. Several plants were able to maintain partial service, by distributing from storage, clear, filtered water or by filtering stored raw water supplies. Of course, it was necessary to cut down the pressure and in a good many instances, supply water only one or two hours a day under greatly reduced pressure. The availability of stored clear water or water for filtration was a most helpful asset in this emergency. Supplementary or industrial well supplies were used in a large number of cases, both for pumping into distribution systems and for filling tanks and containers for distribution to consumers throughout the town limits. Water was also shipped in tank cars and trucks from towns hundreds of miles distant. This water was usually distributed by establishing neighborhood dispensing stations where people could come and get it.

We attempted to chlorinate all these emergency supplies as soon as they were found. In some of the larger towns it was impossible to ascertain where all of this water was coming from because wells of which we had no knowledge before were pressed into service. In addition to the high chlorine content, boiling of all drinking and

culinary water was urged, if for nothing else, to boil off some of the excessive chlorine.

Emergency plant operations varied depending upon local conditions. One of the outstanding feats of the whole flood in Kentucky was the operation of the Louisville pumping plant under the most adverse conditions. The 24 m.g.d. triple expansion, vertical steam pump was operated, practically submerged, including part of the fly wheel, by steam supplied from a river tow boat drawn up to the pumping station.

Emergency supplies were used from any available source. In one case an abandoned sand pit in a small town furnished a source of raw water for the filtration plant. In all cases we endeavored to keep close laboratory checks on the water treated and on possible sources of pollution of treated waters. We were not always able to keep up with these potential sources of pollution. Instances were found where hotels had fire engines placed in the street to pump flood water into the hotel supply systems. Two such cases were found in Louisville. All the faucets were closed and sealed in these buildings, the raw water being allowed to be used only for flushing toilets. Later, when the municipal supply was restored, complete cleaning of the entire building piping system and its heavy chlorination were required.

The rehabilitation of the public supplies was handled in various ways depending upon local conditions. Pumping machinery had to be overhauled in a great many cases. Restoration of steam generating plants required much less time and expense as a rule, than for electric power equipment.

Another unusual problem in the flooded towns was that of checking the sanitary quality of the water in distribution systems after the supply had been restored. We required that the water be heavily chlorinated and that this chlorinated water be drawn through the entire distribution network up to the far ends of the system before being made available for domestic consumption. The chlorine content was meanwhile traced by the orthotolidin test with occasional samples being analyzed for coliform organisms by the presumptive test. When all samples were clear, the supply was opened up for public use.

There were numerous cases where the pollution in the distribution system was intense. Some of these instances were no doubt caused by breaks in the smaller mains or services of the distribution system,

through which flood water entered. However, there were cases where back siphonage from sewers or from toilets in house connections was indicated.

SUMMARY AND CONCLUSIONS

There were many urgent sanitation problems that arose and which had to be met promptly in the flood emergency. There are many individual instances where we could have done a much better job in the light of our present experience. Yet, it must be conceded that we have had very few contagious or infectious diseases that can be directly attributed to the flood. So far as can be learned in the state of Kentucky, one case only of typhoid fever has resulted. That occurred in Paducah and was contracted by a man who had been working in the flood waters for a considerable time rescuing refugees and salvaging property.

Such a widespread disaster brings out in clear relief, certain features that might be considered in preparation for future emergencies in the interest of saving both lives and property.

One such need is the formation of general plans of properly equipped organization that can be called into emergency service on short notice. Units of such an organization would be concerned not only with sanitation and medical care but with the operation of all municipal services, utilities and governmental functions integrated in such a way that they could move smoothly in any devastated area.

As concerns public water supplies, consideration could well be given to such items as locating water purification systems above any possible flood level. More general protection of pumping equipment from flood damage or the provision of emergency pumping equipment would have been of inestimable value in many cases. Provision of private standby power sources independent of the general electric distribution system appears to be clearly indicated. Many plants experienced considerable delay in restoring service because of difficulties in establishing power connections to the net work systems. Obviously, much electrical equipment could be located so as to eliminate the possibility of its damage by flood. Certainly such parts should be so placed as to permit rapid removal if the occasion requires. In extreme cases emergency replacements could be held in reserve. Provision could also be made for ample reserve disinfection equipment in locations entirely separate from the regular plant facilities together with stores of chlorine available in cases of emer-

gency. Dependency on single connecting lines between water plants and distribution systems is also open to question.

Adequate clear water storage for emergency use; close checks on the distribution system with rigid inspections to eliminate potential and existing cross connections and back siphonage; definite and specific information concerning sources of satisfactory emergency supplies from wells, industrial plants and adjacent public supplies are some other factors that are of importance. Many other individual items could be enumerated that would greatly facilitate operations under conditions of disaster. The extent to which they should be provided in any instance must depend on local conditions and upon the estimate of their worth balanced against the benefits that would accrue if they should be made available.

WATER SUPPLIES OF NORTHEASTERN NEW JERSEY*

By Charles H. Capen, Jr.
(*Engineer, North Jersey District Water Supply Commission*)

With the advancement in the art of modern planning methods, entire communities and cities may be conceived in brief form almost over-night. Construction may, if necessary, be consummated in a very short time and all parts of the picture can be so designed and incorporated within the whole that a composite will result that is almost complete in every detail. To the layman, this type of planning, which received its greatest impetus during the war period, is a marvel of modern scientific methods. However, the art of designing for the future requirements of existing municipalities is one that has only lately received public attention in spite of the fact that for many years engineers have struggled, often without success, to bring about a true appreciation of its value.

Whenever the spontaneous growth of centuries has to be overcome, whether it be in the matter of alleviating traffic congestion in Boston, building subways in New York or satisfying water supply needs in New Jersey, the answer is not a matter of precise or immediate determination. It is the last problem with which this paper is concerned and recognition of its rightful importance is steadily gaining, while concurrently rapid growth of population is making the ultimate solution more difficult.

NEW JERSEY AND ITS METROPOLITAN AREA

Some idea of the degree of congestion in the State as a whole may be ascertained by noting that while New Jersey is the 45th state in the Union in area, it is 9th in population, 5th in rate of increase in population and second in density of population. Three quarters of the population responsible for these conditions is concentrated in the northeastern part of the State and the water supply problems are correspondingly difficult.

* Preprint of a paper to be presented at the New Jersey Section meeting, Atlantic City, October 15, 1937.

West of the Hudson River and New York Bay, there radiates from New York City almost in the shape of a semicircle, that portion of northeastern New Jersey generally known as the Metropolitan Area. It is roughly 25 miles in radius. Fifty years ago it was generally considered to include all of the counties of Essex, Hudson and Union and the lower and more populated portions of Bergen and Passaic. More recently, for the purpose of water supply studies, it has included also the northerly and more populated part of Middlesex County, as well as parts of Morris and Somerset Counties. In this area there are more than 150 separate municipalities, having a population of about three million, and supplied with water by 38 separate systems.

Topographically the elevations vary from sea level to nearly 700 feet. Large sections of meadow areas, which are in course of intensive development for industrial purposes, serve to accentuate the concentration of water supply uses. On the other hand, residential areas on the hillsides, where distances between buildings are greater, rock plentiful, and use of water less, must also be adequately supplied.

Enough has been said to indicate that the physical, social, economic and political variations of the area in question are of a nature without many parallels. In this seething whirlpool of conflicting interests, the water works engineer labors sometimes fruitlessly, to bring some semblance of order out of chaos. At the present time one of the periodic efforts along this line is now producing a controversy that threatens again to delay action and progress.

So much has been said about the water supply of this area that is misleading and so much left unsaid that may be enlightening, that an exposition of the entire situation, presented in as dispassionate and impartial a way as possible, seems to be timely.

EARLY SUPPLIES

The first attempt to establish what might be loosely termed a public water supply in this area, was made by Peter Stuyvesant in in 1669. Wells were dug at a location now known as Bergen Square in Jersey City and were used for about two centuries. Practically all of the early sources were merely community wells and little was accomplished in the advancement of the art of municipal supplies until about 1800. The efforts of that day were spurred on by the accomplishments in New York and Philadelphia, shortly prior thereto. As a result of this stimulation, public water systems were

established in a few of the larger cities and one or two smaller communities, much of the development being done by private companies.

DEVELOPMENT AFTER 1850

For reasons that are not now entirely clear, the movement lagged for many years and it was not until nearly 1850 that the real comprehensive exploitation of water supplies began. Profiting by the experience of New York City with its Croton development (1842), communities in New Jersey sought to improve their own conditions. Between 1850 and 1870 new supplies were initiated at Jersey City, Elizabeth, Paterson, New Brunswick, Hackensack and Newark, in some instances by municipal and some by private enterprise. Co-operation between various municipalities failed dismally and the success of many of the early ventures was clearly attributable to the ability of private capital to extend mains into more than one municipality.

In the early days of water supply in New Jersey, as elsewhere, the tendency was toward development of sources near at hand. As growth of population gradually brought about pollution of many of such supplies, sources at a greater distance were sought. A case in point was that of Jersey City where wells had become inadequate or polluted. Pumps were erected on the Passaic River, opposite Belleville, and started delivering water in 1854 from a point over five miles from the city limits—a long distance for those days. Newark, following suit, began pumping from the Passaic River at Belleville in 1870. For these two cities the question of quantity had been solved but not that of quality. The lower Passaic was receiving a continually increasing pollution load and it became evident that a radical change would be required.

The first progressive step toward a consideration of a lasting supply was made when Newark in 1879, engaged Croes and Howell, eminent consulting engineers of that period, to study and report on the best future source for that city. This report covered a wide range of territory and recommended that Newark obtain the Rockaway and Pequannock River watersheds with consideration of the future development of the Wanaque and Ramapo Rivers. Recognition had also been accorded this same problem in the 1868, 1874 and 1876 reports of the Geological Survey. Further recommendations were brought forth in the 1884 report of the first State Water Supply Commission and in the very complete 1894 report by Vermeule on

water supply for the Geological Survey. Before the latter report was submitted, Newark had in 1889, contracted with the East Jersey Water Company to obtain a supply of 50 million gallons per day (M.G.D.) from the Pequannock watershed with provisions for the City to obtain outright ownership in 1900, a right which was then exercised. Water was first delivered to Newark from this source in 1892.

A new era of water activities seemed to be ushered in by leadership of Newark. Probably either because of necessity, competition for industry and population, or improvement in the art, or a combination of these, other communities became water conscious and during the

Boonton Reservoir Spilling Flood Waters Going to Waste on Account of Limited Storage Capacity

next two decades there occurred the greatest proportionate growth in water supplies that this territory has ever known. The two most important of these activities were carried out by the Passaic Water Company and by Jersey City. The former, in association with other companies, started plans for the Little Falls development in 1897, under the direction of the late Clemens Herschel, and the system was first placed in operation in 1899 although it was not fully completed until 1902. Jersey City, in 1899, contracted with a private corporation for the construction of a 50 M.G.D. supply from the Rockaway at Boonton and delivery of water began in 1904.

WATERSHEDS

For the portion of the state that has encountered most of the difficulties in water supply, i.e. the northeastern section, there are

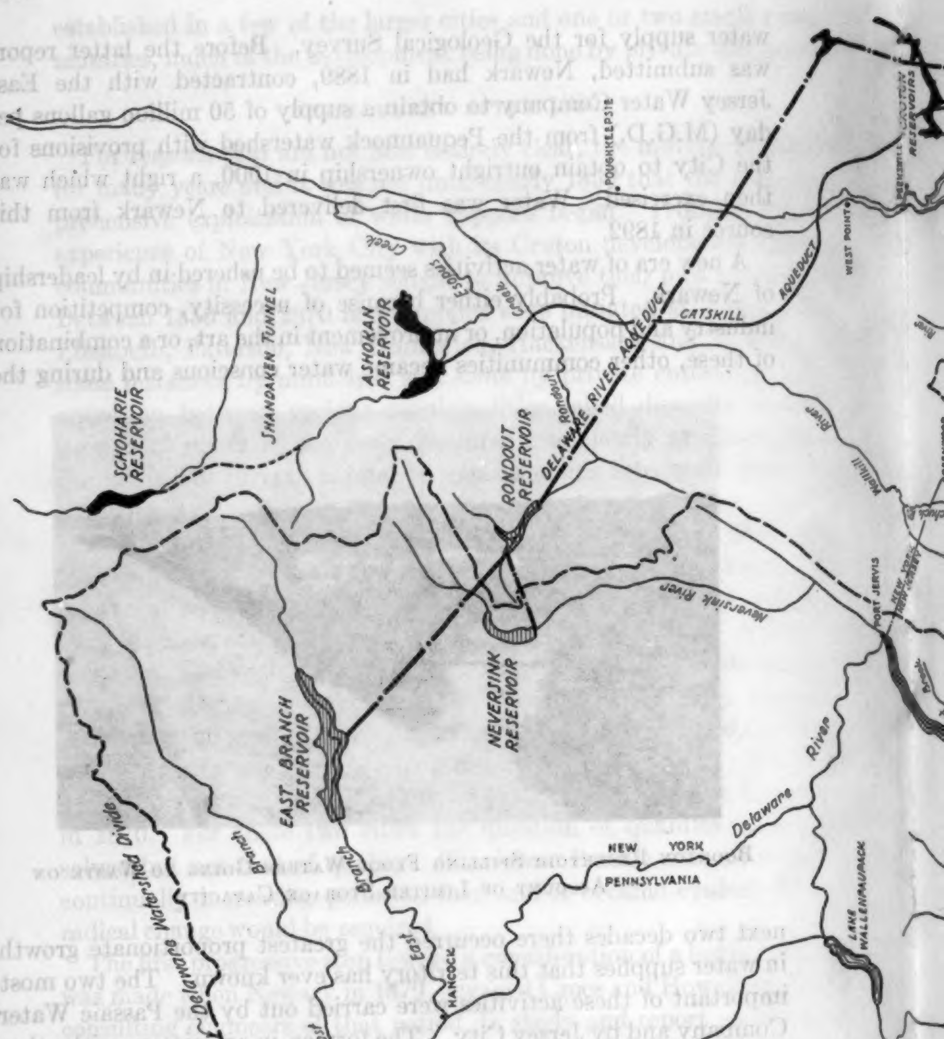

SCHOHARIE RESERVOIR
SHANDAKEN TUNNEL
ASHOKAN RESERVOIR
Esopus Creek
POUGHKEEPSIE
CATSKILL AQUEDUCT
WEST POINT
CROTON RESERVOIRS
RONDOUT RESERVOIR
Rondout Creek
DELAWARE RIVER AQUEDUCT
Wallkill River
Neversink River
NEVERSINK RESERVOIR
EAST BRANCH RESERVOIR
PORT JERVIS
NEW YORK
NEW JERSEY
Delaware River
NEW YORK
PENNSYLVANIA
LAKE WALLENPAUPACK
Delaware Watershed Divide
West Branch
East Branch
HANCOCK
NEW YORK
PENNSYLVANIA

FIGURE 1
EXISTING & PROPOSED WATER SUPPLIES AND WATERSHEDS IN NORTHEASTERN NEW JERSEY AND CONTIGUOUS AREAS

several outstanding topographical features that are fundamental in any consideration of the problem. In the first place there are only two main drainage basins, the one delivering run-off into New York Bay and the other into [illegible] Bay. The latter [illegible] needed great attention except from the [illegible]. The former may be readily divided into [illegible] River Basin (b) Hackensack River Basin (c) Raritan River Basin and (d) tributaries of Hudson River and New York Bay. The Raritan River Basin is the only one of the larger basins which lies wholly within the state. The location of these areas is shown in figure 1. All of the others involve inter-state problems and this fact has had an important bearing on the whole matter of water supply.

[illegible] of its size and its location contiguous to many of the larger communities the Passaic River has received the greatest attention and the greatest development. The principal progressive stages of use of the river and its tributaries are given in table 1. (This table omits some of the smaller uses as well as all ground water supplies.)

The Hackensack River was first developed as a source of water supply by the Hackensack Water Co. [illegible]. The original site of the dam and pumping station at [illegible] is still in use although many improvements and enlargements have taken place in the intervening years. The watershed area above the point of intake is 115 square miles.

The Raritan River is the least intensively developed of all of the larger sources and for this and other reasons is seriously considered for use for the next major project. [illegible] Brook, the plant serving water to the Elizabethtown Water Company, constructed in 1931 with a watershed of 256 square miles on the Millstone River and 490 square miles on the Raritan River, has the right to divert 10 M.G.D. from each of these streams. At Weston's Mills, a private company constructed a pumping station in 1868 to serve the City of New Brunswick, diverting water from Lawrence Brook, a tributary of the Raritan, with a watershed of 45 square miles. This system was later purchased by the City. Somerville and Raritan receive water from the plant of the [illegible] Water Company established in Raritan in 1881, drawing water from the power canal and river with a watershed of 468 square miles. The Bound Brook Water Company in 1889 developed Middle Brook with an area of [illegible] square miles, to serve Bound Brook. There are other smaller munic-

several outstanding topographical features that are fundamental in any consideration of the problem. In the first place there are only two main drainage basins, the one delivering run-off into New York Bay and the other into Delaware Bay. The latter has not needed great attention except from the long range point of view. The former may be roughly divided into (a) Passaic River Basin (b) Hackensack River Basin (c) Raritan River Basin and (d) tributaries of Hudson River and New York Bay. The Raritan River Basin is the only one of the larger basins that lies wholly within the state. (The location of these areas is given in figure 1.) All of the others involve inter-state problems and this factor has had an important bearing on the whole matter of water supply.

By virtue of its size and its location contiguous to many of the larger communities, the Passaic River has received the greatest attention and the greatest total development. The principal progressive stages of use of this river and its tributaries are given in table 1. (This table omits some of the smaller uses as well as all ground water supplies.)

The Hackensack River was first developed as a source of water supply by the Hackensack Water Company in 1869. The original site of the dam and pumping station at New Milford is still in use although many improvements and enlargements have taken place in the intervening years. The watershed area above the point of intake is 115 square miles.

The Raritan River is the least intensively developed of all of the larger sources and for that and other reasons is seriously considered for use for the next major project. Near Bound Brook, the plant serving water to the Elizabethtown Water Company, completed in 1931 with a water shed of 286 square miles on the Millstone River and 490 square miles on the Raritan River, has the right to divert 10 M.G.D. from each of these streams. At Weston's Mills, a private company established a pumping station in 1868 to serve the City of New Brunswick, diverting water from Lawrence Brook, a tributary of the Raritan, with a watershed of 45 square miles. This system was later purchased by the City. Somerville and Raritan receive water from the plant of the Somerville Water Company established in Raritan in 1881, drawing water from the power canal and river with a watershed of 468 square miles. The Bound Brook Water Company in 1889 developed Middle Brook, with an area of 17 square miles, to serve Bound Brook. There are other smaller munic-

TABLE 1

DATE	LOCATION	WATERSHED AREA, SQ. MI.	DISTRICT SERVED ORIGINALLY	REMARKS
1854	Passaic R. opp. Belleville	911	Jersey City	Abandoned 1897
1856	Passaic R. below Great Falls	785	Paterson	Abandoned 1867
1867	Passaic R. above Great Falls	785	Paterson	Abandoned 1898
1870	Passaic R. at Belleville	911	Newark & Belleville	Abandoned 1892
1892	Pequannock R. at Macopin	62	Newark & Belleville	Bloomfield and parts of other municipalities now served
1899	Passaic R. at Little Falls	761	Paterson, Passaic & Clifton, Kearny, Bayonne	Used for industrial water after 1932
1904	Rockaway R. at Boonton	119	Jersey City	Hoboken served after 1924 as well as some smaller users
1907	Passaic R. above Great Falls	785	Silk Dyers in Paterson	Moved to Little Falls in 1932
1930	Wanaque River at Wanaque	94	Kearny & Bayonne	Later Montclair, Glen Ridge, part of Newark and Elizabeth, Paterson, Passaic & Clifton

ipal users on the watershed but they are neligible compared to the large industrial users on the lower parts of the river.

The main tributaries of the Hudson River in New Jersey are the Wallkill and Pochuck. The only development on these is a rather small one of the Franklin Water Company. Studies of these streams indicate that they are neither feasible nor economical as sources of water supply for the Metropolitan Area and need not be considered.

Streams entering the vicinity of New York harbor include the Elizabeth, Rahway and Navesink Rivers. Tribuaries of the latter two are either wholly or partially developed although some parts of the Rahway may eventually have to be sacrificed to the encroachments of population, as was a former supply on the Elizabeth River.

TREND IN THE DEVELOPMENT OF WATERSHEDS

Styles and fads among water supply engineers exist just as surely as among creators of fashions for clothes. The continued success of the Croton supply of New York City, a new style or type involving upland sources with watershed protection, was a constant reminder to New Jersey municipalities that their own difficulties lay primarily in not following the example to the letter. It remained for the 1879 report of Croes and Howell to the City of Newark to point the way clearly toward an upland supply. The City carried out the plan to an almost unprecedented degree by gradually purchasing over 75 percent of the total watershed area of the Pequannock River above the intake.

While later improvements in the art of treating water have indicated that some of this precaution may not be economically justified, nevertheless the basic idea promulgated in the procurement of the Croton supply has affected many of the developments in northeastern New Jersey ever since. This is true because the soundness of the judgment of New York's water engineers of a century ago has never been questioned. Rather, modern methods have merely made possible the use of supplies that would otherwise be passed over as unfit, or the improvement of those that might be questionable.

The Rockaway and Wanaque watersheds, as well as to some extent the Ramapo, were also originally proposed with this viewpoint of obtaining pure upland waters not requiring treatment. The Louisville experiments just before 1900 indicated the possibility of going to the other extreme and the successful use of water from the Little Falls filter plant over a long period of years was unquestionably attributable to the application of experimental methods.

A perusal of the literature on water supplies in this area during the last half of the nineteenth century indicates clearly the continual search for unpolluted waters and as late as 1894, Vermeule in the Geological Survey Report stated:

"The agricultural character of the central valley (above Little Falls), and its large and increasing population forbid that we should consider this supply at the falls as altogether desirable for the future, although at present it is all that can be desired." "The upper Passaic, above Two Bridges, is not a desirable stream as a source of water supply. Too large a portion of its area lies upon the flat central valley. There are large areas of wet land, and the stream becomes quite muddy at times, and a general examination of the gathering grounds would result in its condemnation, although the analyses which we have indicate a fairly good water at present."

The floods of the Passaic River in 1902 and 1903 caused a reconsideration of the entire subject and the matter of flood control and water supply were linked together in the reports of the various bodies that studied the situation at that time. Practically all of the several reports on the same subject made since that time have indicated there is little economic justification for flood control alone, but that linked with water supply such a plan might be feasible. In the earlier part of the present century, objections by the Morris Canal and Banking Company and the Delaware, Lackawanna and Western and the Erie railroads seem to have been to some extent instrumental in preventing further consideration of the plans proposed.

In later years, questions as to potability of water obtainable from these sources seem to have been the chief draw-back. At all times the estimated cost has been moderately large and a certain reticence has always existed as to the expenditure of these sums when competent opinions have differed over so wide a range.

The most prodigious of these plans was that presented by Vermeule in the 1905 Report of the Geological Survey wherein a dam at Little Falls, 6000 feet long, would have created a lake with an extreme flood area of 32,922 acres and a capacity of 327 billion gallons. The estimated average flow would be 306 M.G.D. of which 206 M.G.D. would be used for water supply at a delivery elevation of 184. The balance of 100 M.G.D. would go downstream to satisfy riparian needs.

In reference to quality the report said "It may be assumed that practically all of the water hereafter to be taken from the Passaic

River, excepting possibly the present supply of the City of Newark, will require filtration. This being true, it may be easily shown that the water from the proposed lake, if taken from the dam at Little Falls, will be far superior in quality to the raw water taken from the stream at the same point, or at almost any other point where any considerable quantity can be obtained. This is largely due to the thorough sedimentation which will occur in the proposed lake. The volume of the lake will be fully 10 percent greater than the average yearly discharge of the entire river, consequently the water will oridinarily lie in storage more than thirteen months before discharging at the dam."

Another plan that created considerable interest was the Mountain View project which, while not affording so complete flood control and water supply as the preceding plan, was nevertheless an undertaking of much merit. In 1919, Dr. Kummel, the State Geologist, reporting on these two, said "Neither of these projects received the popular support necessary for an undertaking of such magnitude, and both can probably be regarded as unattainable, at least in the immediate future." The first real move toward construction of the Wanaque project was made by the State Water Supply Commission in 1911 and this gradually culminated in direct action even though the work was eventually done by the North Jersey District Water Supply Commission, being completed in 1930.

In 1921 the City of Bayonne made application to the Board of Conservation and Development for permission to divert 50 M.G.D. from the Ramapo at Oakland. The grant was allowed in 1922 but in 1923 was set aside by the Court of Errors and Appeals. Many other actions and reports have passed into history, some of them still under active consideration. Since these latter will be further discussed, no great detail will be given at present. For the purpose of bringing this part of the subject to a close, while at the same time giving a review of the various steps that have been taken along these lines, table 2 has been prepared showing the more important reports, on matters of this nature, most of which have not been followed by direct action.

YIELD

One cannot help admiring the daring of the early engineers in estimating quantities of water in spite of the lack of hydrologic data. As late as September 1936, the Water Resources Committee,

TABLE 2

List of More Important Printed Documents on Water Supply for Part or All of Northeastern New Jersey

DATE	REPORT TO	REPORT BY	ENGINEER	RECOMMENDATIONS
1879	City of Newark	Croes and Howell	Croes & Howell	Dam on Rockaway R.
1884	State	State Water Supply Commission	Ward	Dam on Pequannock R.
1894	State	State Geological Survey	Vermeule	Dam on Wanaque R.
1903	State	State Geological Survey	Vermeule	Dam at Little Falls
1904	State	Northern N. J. Flood Commission	Gowen & Sherrerd	Dam at Mountain View
1905	State	State Geological Survey	Vermeule	Dam at Little Falls
1907	State	Passaic River Flood Commission	Gowen & Sherrerd	Dam at Mountain View
1908	State	State Water Supply Commission	Benzenburg, Davis Newell & Sherrerd	Dam at Mountain View
1909	State	Sate Geological Survey	Vermeule	Dam on Wanaque & Ramapo
1911	State	State Water Supply Commission	Sherrerd	Dam on Wanaque
1922	State Department of Conservation & Development	Hazen, Whipple & Fuller	Hazen	Dam at Long Hill
1922	City of Bayonne	Citizens Committee	Potts	Dam on Ramapo R.
1923	City of Elizabeth	Water Investigating Committee	W. E. Fuller	Dam at Stony Brook
1924	City of Bayonne	Citizens Committee	Weston	Abandon Ramapo—join Wanaque
1924	City of Elizabeth	North Jersey District Water Supply Commission	Sherrerd & Pratt	Dam at Stony Brook
1925	Wanaque Participants	North Jersey District Water Supply Commission	Sherrerd & Pratt	Dam at Chimney Rock
1926	State	Water Policy Commission	Hill	Obtain lands for a large development (site not named)
1929	Bergen County	North Jersey District Water Supply Commission	Sherrerd & Pratt	Dam at Mahwah
1929	State	State Water Policy Commission	Sherrerd	Dam at Bunnvale, Vernoy or Ralston
1930	Cities of Bayonne, East Orange, Elizabeth & Newark	North Jersey District Water Supply Commission	Pratt, Fuller & McClintock & W. E. Fuller	Dam at Chimney Rock
1931	State	State Water Policy Commission	Sherrerd, Barbour, Gregory, Smith & Bassett	Dam at Bunnvale

as a branch of the National Resources Committee, issued a detailed report on "Deficiencies in Basic Hydrologic Data." Nevertheless, more than 100 years ago the Morris Canal was planned and constructed. From many standpoints the canal was a hydraulic achievement that ranks high in the annals of American practice. It is true that the water supplied by Lake Hopatcong was not sufficient and that Greenwood Lake had to be constructed to supply the additional needs but it seems that this deficiency was caused more by excess quantities required for leakage and lockage than by any errors in estimates of stream flow.

Hydrologic data in the area under question appear to have begun with rainfall records at Newark in 1843. Other rainfall records began at Lake Hopatcong in 1846 and New Brunswick in 1854. At Philadelphia reliable records started in 1825 and at New York in 1836. Early stream flow records were not always reliable but appear to have been accepted after 1877 on the Passaic River and 1868 on the Croton. In preparing their 1879 report, Croes and Howell gaged the Passaic River at Paterson and found that at a very low stage of the river the flow was 195 cubic feet per second for a period of 10 to 12 days. This was somewhat higher than was later found to be a safe figure. It is certain that these early reports all had to rely on many approximations. In 1894 the Water Supply report of the Geological Survey by Vermeule went to great length to establish tables and rules to guide in the determination of yields. The only material difference between the estimates in the report and those of today are in respect to the total quantity developed. Vermeule preferred to stay well on the safe side and utilize generally about 14 inches annually from any one shed whereas the tendency today is to increase this to full development. The 1894 report used a period of 18 months as the maximum length of draw-down for a reservoir whereas modern methods call at times for periods as long as five or six years between overflows of fully developed reservoirs.

YIELD OF PEQUANNOCK WATERSHED

When the East Jersey Water Company contracted to develop a supply to serve 50 M.G.D. to Newark, not only was it necessary to make certain approximations as to storage and run-off but also as to aqueduct carrying capacities. Large diameter steel pipe such as was used, was somewhat of an unknown quantity and the company's

engineers appear to have been over optimistic. At any rate, it soon became evident that the original 48-inch line must be paralleled by a 42-inch line, one being completed in 1892 and the other in 1896.

The City of Newark decided in 1900 to exercise its option for the purchase of the supply. However the City was not convinced that the guarantee of 50 M.G.D. could be met. The company controlled the following reservoirs:

	M.G.
Clinton	3,518
Oak Ridge	2,555
Canistear	2,407
Echo Lake	612
Macopin	32
Total	9,124

It proposed to retain Canistear and Echo Lake, claiming that the others were sufficient to yield the guarantee of 50 M.G.D. Vast legal and engineering fortresses were built up for the battle. John R. Freeman, reporting to the City, admitted that on the basis of the run-off records compiled during the period of operation of the Pequannock (1892–1899) a storage of 6,000 M.G. would be sufficient. However he pointed out that the driest year of the period of record, 1895, was not nearly as dry as the 1880–1883 period as indicated by the Croton records, and that an additional volume of at least Canistear and Echo Lake would be required, perhaps even as much as 12,000 M.G. in total. Freeman drew attention to the fact that the Pequannock was the most prolific of all recorded eastern streams and that the provision of additional storage at Charlotteburg would materially increase the yield because of the lack of adequate storage on the lower parts of the watershed. The City also retained Desmond Fitzgerald, J. J. R. Croes and Frederick P. Stearns as consultants on this same question. Finally the Company yielded before the suit came to trial and deeded Canistear Reservoir, and 1,000 acres of additional lands around the reservoirs. It is not clear what value these could have been to the Company. In 1918, the City again retained Freeman to review the capabilities of its supply, particularly in view of its enlarged reservoir capacity and increased needs. At that time the capacity of the reservoirs was as follows:

	M.G.
Oak Ridge	3,850*
Clinton	3,518
Canistear	2,407
Echo Lake	612
Macopin	32
Cedar Grove	679†
Total	11,098

* Added to in 1918.
† Completed in 1904.

Freeman pointed out the following salient facts:

1. Much water runs to waste from Pequannock shed.
2. Verifying the 1900 report, the 1900 dry period would have required drawing Canistear down completely to yield 50 M.G.D.
3. The worst period of record is May 1, 1899 to April 1, 1902. This would permit a yield of 1.2 M.G.D. per square mile (uncommonly high). Additional storage could be obtained at Charlotteburg or Newfoundland but the railroad problem to be solved would be difficult.
4. A longer period of depletion, June 1908 to April 1914, would have occurred under a draft of 75 M.G.D. but the required storage would only be 14 B.G. Periods of draw-down of that length are permissible.

By the most singular coincidence, the dry period of 1900–1901 was in progress while Freeman was preparing the first of his reports and its ultimate outcome precisely bore out his predictions. In 1918 the second important dry period was taking place, also while he was preparing a report, which again substantiated his general viewpoint. While other dry periods have since occurred, in 1923 and 1932, the 1900 period still governs in this region for developments of 0.8 M.G.D. or less per square mile. Thus the Pequannock yield is still subject to the 1900 period because of incomplete storage. Figure 2 has therefore been prepared to show the effect of this period. The run-off as corrected for storage and diversion is shown, together with the effect of storage as now available. This curve is slightly ambiguous for the reason that the watershed area was increased from about 62.4 to 63.7 square miles after 1900 and a correction factor should be applied. With this correction and allowance for the

possibility of other steps that would be taken to obtain water under conditions of severe drought, a yield figure of 55 to 56 M.G.D. would be possible. Newark assumes it at 57 M.G.D. but this seems to be slightly high.

Table 3 shows the rainfall and run-off in inches for several of the watersheds in this area. It is clearly indicated that the Pequannock

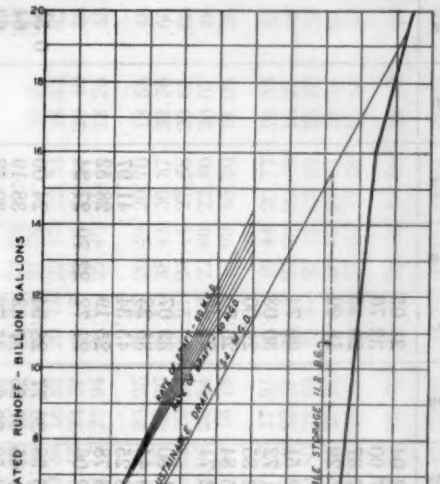


FIG. 2. YIELD OF PEQUANNOCK SUPPLY

is slightly more prolific than the others both in rainfall and run-off. The average run-off approximated 50 percent of the rainfall in the dry periods.

YIELD OF ROCKAWAY WATERSHED

The Rockaway watershed, with an area of 119 square miles and a total maximum storage of 8,300 M.G. at Boonton Reservoir with

TABLE 3

Comparative Rainfall and Run-off

	Rainfall, Inches						Run-off, Inches					Ratio Run-off to Rainfall			
	Rockaway	Pequannock	Wanaque	Ramapo	Hackensack	State of N. J.	Rockaway	Pequannock	Wanaque	Ramapo	Hackensack	Rockaway	Pequannock	Wanaque	Hackensack
1892	39.38	45.41				42.04		21.05					0.46		
3	53.71	50.35			48.09	47.90		32.76					.65		
4	42.99	45.71			45.00	47.37		28.35					.62		
5	36.45	37.51			41.20	37.29		18.90					.50		
6	49.34	52.17			49.51	42.51		30.74					.59		
7	59.98	59.23			51.13	51.72		30.03					.51		
8	50.81	52.55			53.19	52.35		29.00					.55		
9	44.97	48.71			44.73	45.84		26.70					.55		
1900	42.65	43.30			51.84	42.71		21.47					.50		
1	63.27	64.18			55.82	51.80		32.07					.50		
2	64.60	60.44			58.32	59.44		35.23					.58		
3	69.25	64.78			64.56	56.25		45.34		41.97			.70		
4	48.73	45.24		42.41	40.84	43.78		25.19		28.52			.56		
5	48.12	44.38		39.89	40.21	42.06		22.72	22.70	27.24			.51		
6	48.65	49.81		46.37	47.56	46.38	26.77	28.94		24.00		0.55	.58		
7	58.97	54.47		54.69	48.46	51.65	37.55	37.33		38.19		.64	.69		
8	48.90	48.91		47.34	46.60	42.58	30.68	25.70		30.52		.63	.53		
9	46.07	46.48			41.00	40.86	24.58	24.60		21.36		.53	.53		
10	42.32	39.29			39.11	39.73	23.08	24.41		29.49		.55	.62		
11	50.32	51.40			46.23	50.36		29.36		25.13			.57		
12	50.19	46.65				46.61		24.19		30.48			.52		
13	46.83	49.92		55.27		46.99	26.48	28.53	28.90	26.36		.57	.57		
14	39.77	38.70				39.23	21.64	23.83	24.76			.54	.62		
15	53.36	47.98				47.37	27.84	28.13				.52	.59		

16	37.81	38.08				38.17	25.89	28.96				.68	.63		
17	37.43	39.08				40.80	17.80	20.14				.48	.52		
18	37.73	37.13				37.65	17.58	17.92				.47	.48		
19	57.12	53.14			43.65	52.10	32.52	29.97				.57	.56		
20	56.57	58.01			42.45	51.87	36.26	35.42	38.11			.64	.61		
21	43.07	45.50	50.09		34.50	38.16	22.41	21.75	24.82			.52	.48	0.50	
22	44.76	44.32	44.49		37.79	41.57	22.27	22.46	21.79		16.79	.50	.51	.49	0.44
23	39.90	40.31	44.24		33.50	40.38	18.82	20.15	22.17	22.34	18.44	.47	.50	.51	.55
24	43.78	43.18	47.22		36.53	44.17	24.37	23.87	26.09	24.94	20.40	.56	.55	.55	.56
25	49.20	46.13	47.57		40.48	42.15	21.94	23.98	22.40	21.14	18.25	.45	.52	.47	.45
26	48.54	45.20	42.61		39.70	44.41	23.25	22.67	20.49	20.70	18.58	.48	.50	.48	.47
27	53.56	60.88	58.40		51.97	49.68	32.36	36.56	38.43	36.37	32.76	.60	.60	.66	.63
28	49.78	48.84	48.97		47.72	46.22	29.86	28.21	24.44	27.58	29.67	.60	.58	.50	.62
29	42.65	49.29	47.17		45.75	42.96	20.84	25.16	22.89	22.80	20.67	.49	.51	.49	.45
30	35.83	40.38	40.75		40.44	35.28	13.78	16.78	14.93	15.36	14.04	.38	.42	.37	.35
31	41.80	42.99	43.81		36.64	37.07	17.91	20.64	19.44	20.77	16.33	.43	.48	.44	.45
32	46.30	52.32	46.42		41.15	46.80	22.57	22.40	21.90	22.49	15.25	.49	.43	.47	.37
33	48.10	54.18	50.76		53.88	49.80	28.59	29.84	27.13	25.02	23.82	.59	.55	.53	.44
34	50.17	52.87	49.58		49.96	45.43	27.23	27.17	26.42	27.21	24.34	.54	.51	.53	.49
35	39.54	42.46	37.07		31.86	42.32	21.14	20.72	17.53	17.21	13.84	.53	.49	.47	.43
36	48.92	54.70	49.19		48.00	47.57	29.50*	30.08	26.83	28.00*	22.80*	.60	.55	.57	.48
Average........	47.83	48.37	46.77	47.66	45.10	45.10	25.02	26.65	24.61	26.21	20.40	.54	.55	.50	.48
Average from 1921 to 1936..	45.37	47.72	46.77		41.87	43.37	23.55	24.53	23.61			.52	.51	.50	

* Approximate.

flashboards, and 250 M.G. at Split Rock Pond, is contiguous to the Pequannock and somewhat similar although less rugged in topography. Here again the storage ratio is low. No more than casual studies are required to show that the 1900 dry period would also govern this yield. Therefore by careful comparison of Rockaway and Pequannock records in table 3, a ratio has been worked out between the two and applied to the run-off figures of the latter so as to obtain theoretical figures for the former. To show the relation-

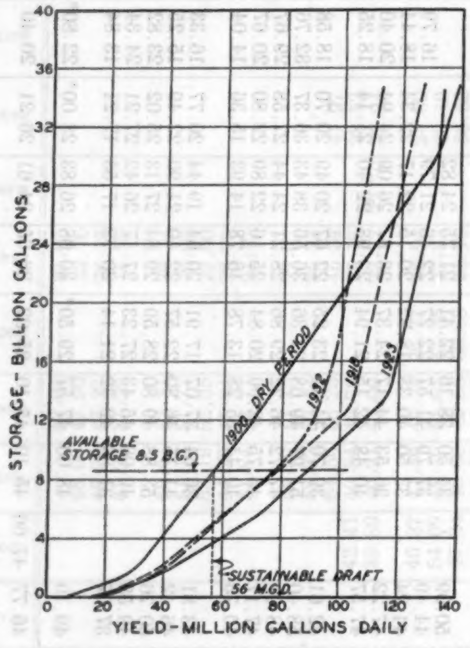


FIG. 3. ROCKAWAY SUPPLY. RELATION OF STORAGE TO YIELD—VARIOUS PERIODS

ship between the dry periods as affecting the yield for different values of storage, figure 3 has been prepared using the theoretical figures for the 1900 period and actual records for all others. These curves are of particular value in the case of the Rockaway because of much agitation in the past with reference to the effect of adding storage on this shed.

It is interesting to note that from this figure, the yield of the Rockaway is found to be 56 M.G.D. whereas Sudler's method gives 63

M.G.D. for a 99 percent year and 71 M.G.D. for a 95 percent year. It must be concluded, therefore, that the single year of 1900 is unique. A comparison of its run-off characteristics with those of other years indicates that this is true.

YIELD OF WANAQUE WATERSHED

When the original diversion right for the Wanaque project was applied for in 1916, a total of 50 M.G.D. was sought and granted. As other municipalities became interested and signified their intention of participating, various plans were considered and finally it was decided to develop the watershed of 94.4 square miles to the full

TABLE 4

Yield of Wanaque Supply as Estimated by Various Methods

METHOD	STREAM RECORD USED	PERIOD OF RECORD	GROSS YIELD IN MILLION GALLONS DAILY	
			Without Flash-boards	With Flash-boards
Mass Curve	Pequannock	1892–1926	104.1	105.7
	Wanaque	1920–1926	105.1	105.9
Sudler's 95%	Pequannock	1892–1926	107.5	109.3
	Wanaque	1920–1926	102.5	103.3
Sudler's 99%	Pequannock	1892–1926	100.5	102.3
	Wanaque	1920–1926	96.3	97.5
Mass Curve	Wanaque	1920–1936	91.6	92.9

extent of its yield. Immediately it became necessary to review this feature carefully.

Studies based on the few records available for the Wanaque, indicated a very close relationship between the rainfall and run-off of the Wanaque and Pequannock watersheds. Furthermore they are adjacent and similar in topography. By 1922 there was a 30 year record of Pequannock run-off and yield available. By trial it was found that the 1900 dry period governed for partial developments of the shed and the 1918 period for full developments. Accordingly the Pequannock records for these periods were reduced to a square mile basis. Suitable corrections were made for differences in water surface and ratios of run-off for the two sheds, and a theo-

retical mass diagram was prepared for the Wanaque. From this it was determined that a total yield of 107 M.G.D. could be obtained for complete use of the Wanaque watershed.

With allowances for compensation water, the net yield of the Wanaque was estimated to be 100 M.G.D. for a final watershed area of 94.4 square miles. This conclusion later precipitated much argument as to the ability of the shed to deliver the estimated quantity. The discussion reached a white heat when differences of opinion arose as to the type and capacity of the aqueduct. Estimates given by various consultants ranged from 72 to 100 M.G.D. A complete

WANAQUE AQUEDUCT—COMPLETED LINES BEFORE BACKFILLING

resumé of this was given in the Engineering News Record (1). The method of computing yields as developed by Sudler (2) (founded partly on an earlier method by Hazen (3)) had just been published and was used in the controversy. Various estimates made at that time by the writer (together with later additions), are presented in table 4. Results obtainable by normal methods were constantly subject to revision during part of the period of controversy by virtue of the fact that the 1926 dry period was in progress and it was not certain what the outcome of its effect would be.

In the period from 1929 on, another dry period occurred which

affected the whole country. This has been termed the 1932 dry period (that being the year of maximum depletion for the Wanaque) and has been found to govern for the Wanaque because of its full development. Figure 4 shows the mass diagram for the watershed for the period of record.

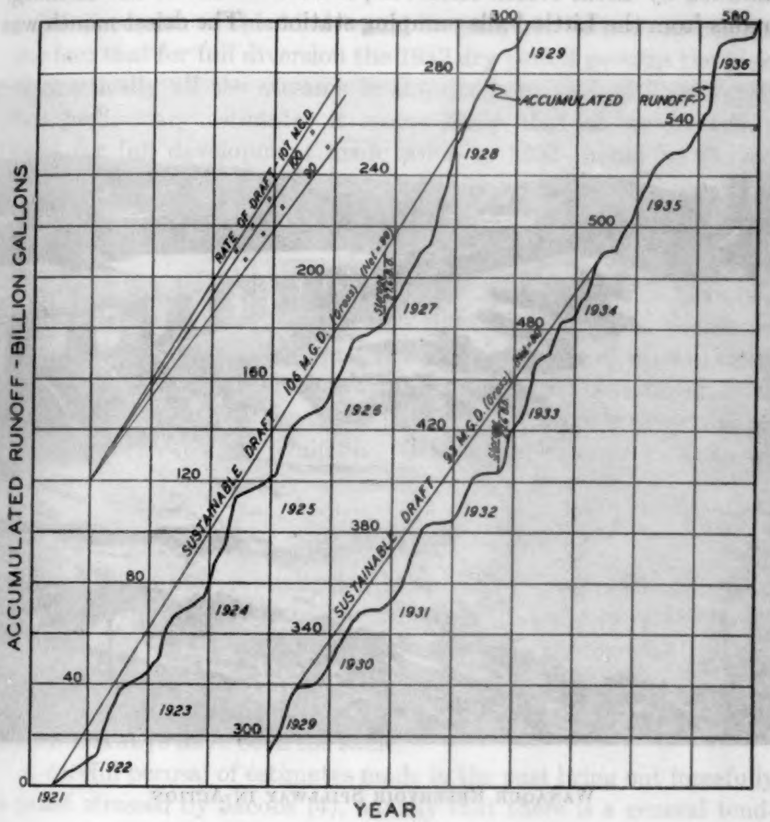


FIG. 4. YIELD OF WANAQUE SUPPLY

YIELD OF PASSAIC WATERSHED

The yield of the Passaic River at Little Falls has long been the subject of much controversy. In establishing the value of certain water rights and grants prior to the purchase of the Little Falls plant by the three cities of Paterson, Passaic and Clifton, the North Jersey District Water Supply Commission in 1928, made certain calcula-

tions and determined that the 1923 dry period governed the yield of the river. The gross watershed area is about 760 square miles but complete dry weather diversion from the Pequannock and Rockaway sheds eliminated 183 square miles of area. There is no storage available on the river proper although a storage of 150 M.G. is afforded by Great Notch Reservoir, located on one of the discharge mains from the Little Falls pumping station. The driest month was

WANAQUE RESERVOIR SPILLWAY IN ACTION

August 1923 when the minimum flow of the river was 6 M.G.D. and the diversion was 40 M.G.D. giving a gross yield of 46 M.G.D. Correcting this for subsequent Wanaque diversion would have given a yield of 43 M.G.D. The driest week, with Wanaque deducted, would have given a gross river yield of only 31 M.G.D.

By 1932 Wanaque water was actually being diverted and the records for that year indicate that while the flow characteristics varied somewhat from those of 1923, a yield of 40 M.G.D. would

probably be the highest that could be considered as a safe figure for the Little Falls plant, as at present constituted. It seems to be generally claimed that diversion rights at this location amount to 75 M.G.D.

YIELD OF OTHER WATERSHEDS

No discussion of this kind would be complete without mentioning the fact that for full diversion the 1932 dry period governs the yields of practically all the streams in the northern part of New Jersey. For preliminary estimates it seems likely that all predictions of yield for full development made prior to 1932 should be reduced about 15 percent.

GENERAL COMMENT ON YIELDS

Some engineers who have studied the problem of yields have concluded that while methods such as those of Hazen and Sudler are excellent for certain approximations, particularly where actual measurements are either absent, meager or unreliable, nevertheless no method can entirely supersede the mass diagram where reasonably long term records are available. The writer concurs in this conclusion.

POPULATION

Increasing water consumption is so inter-related with increasing population that a study of one would be incomplete without due consideration of the other. Practically all the reports listed in table 2 have given some attention to the matter of growth of population even though the degree of importance attached to the subject may not always have been the same.

A careful perusal of estimates made in the past bring out forcefully a point stressed by Jacobs (4), namely that there is a general tendency to overestimate future growth. Figure 5 amply demonstrates this contention. There is no desire to belittle the earlier estimates or to suggest that the one shown by the writer is unlikely to be proven faulty in the future. Rather, unusual conditions, known all too well by everyone who has given thought to the question, have definitely changed the trend in a way that probably could not have been anticipated. Certainly the estimate made by Vermeule in 1894 (based on the 1890 census) was remarkably accurate for the

period up to 1920. Most of the others, too, appear reasonably logical as extensions of the existing curve, but sight must not be lost of the changes that have been taking place since the world war. Recent estimates in various municipalities indicate that the rate has definitely diminished—hence the present drastically reduced prediction advanced in figure 5. An excellent exposition of the predic-

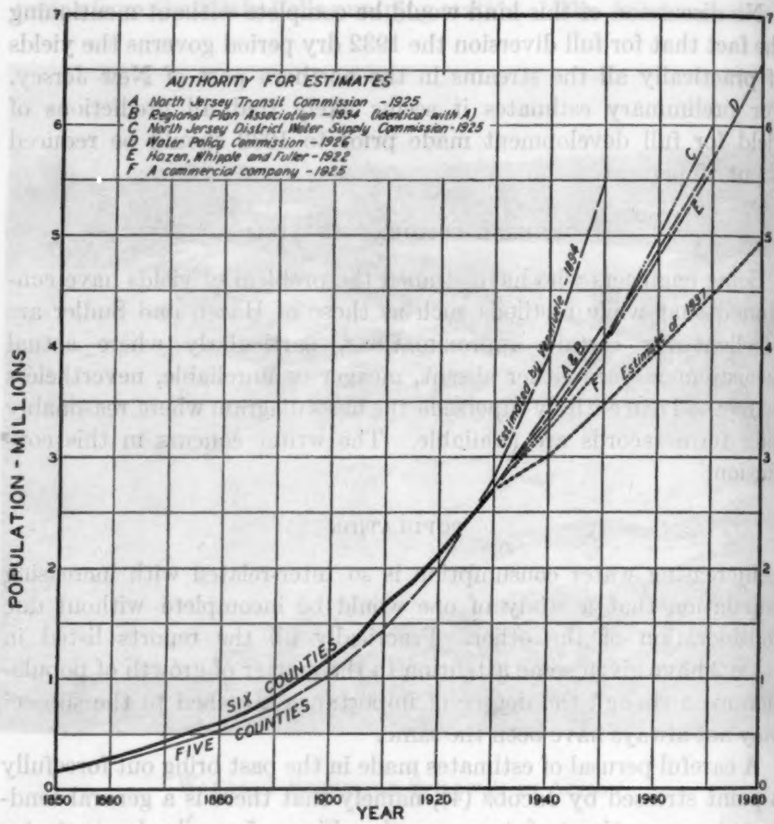


FIG. 5. POPULATION

tions of population by mathematical formulae, based on the skew frequency method, has been given by Goodrich (5). The writer has drawn a curve by this method but has not presented it herein because it tends to give what is believed to be too high an estimate for the future. Presumably this is because of the difficulty of incorporating in such an estimate, a true appreciation of the events of the last two

decades. The results shown in figure 5 are offered, therefore, with the caution that the census of 1940 will probably throw much additional light on the subject and definite predictions can be better made at that time.

GROWTH IN USE OF PUBLIC SUPPLIES

The brief historical outline of public water supply development in some of the preceding paragraphs, will serve to show in a general way how the trend grew. In order to give a more vivid illustration,

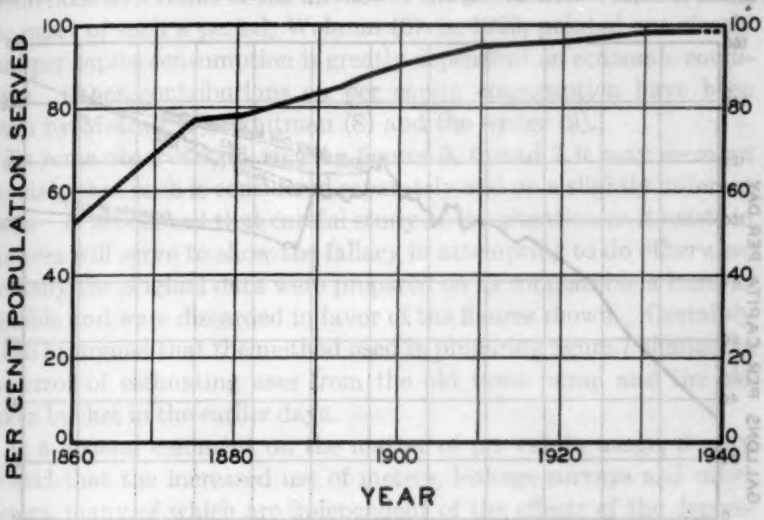


FIG. 6. GROWTH IN USE OF WATER

however, figure 6 has been prepared showing the percent increase in users during the last three quarters of a century.

For the purpose of establishing a fairly definite basis of comparison, the population used in the preparation of figure 6 has been that of the six counties, plus contiguous areas in Morris and Somerset, i.e. that of the presently constituted area defined in preceding paragraphs. If the basis of five counties (with certain deductions) were used for the earlier years, the curve would indicate somewhat higher percentages up to about 1910. This however would give a non-uniform type of comparison.

In any event, all but about two percent of the residents of the area as defined for figure 6, are now served by one of the established

supplies and it is not anticipated that this situation will change materially within a reasonable period of time.

PER CAPITA CONSUMPTION

Probably in very few other phases of general water supply data can there be so many variations in opinion and information as in the determination of per capita consumption. Vermeule has reported (1909) the average daily per capita consumption as 83 gallons in 1882, 97 gallons in 1894 and 117 gallons in 1905. The corresponding values as illustrated in figure 7 are 80, 95 and 106. However, in

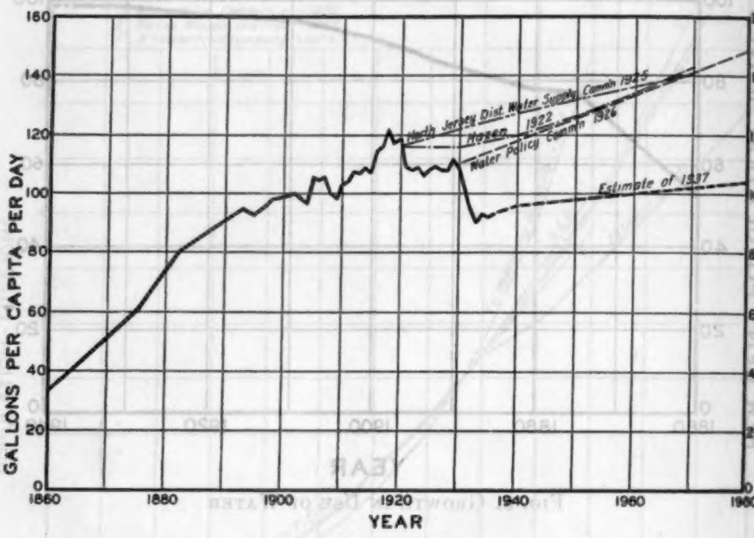


FIG. 7. PER CAPITA CONSUMPTION

estimating for the future, Vermeule used 100 gallons per capita per day in 1894 and again in 1905. It is important to note that he based his per capita estimates on population served and there is so much justification for such a method that figure 7 has been prepared in the same way. Since only two percent of the population in this area are not now served, the error in using this basis as against total population may be disregarded for most practical purposes.

It is well known that distribution systems do not follow the political boundaries used for census figures. Hence estimates of population served are subject to considerable error, particularly as the end of each decade is approached.

In its 1926 report, the first Water Policy Commission attempted to distinguish definitely between total population and population served. Conditions have so changed since then, however, that it seems probable that some of the segregations made then would now be either outmoded or outweighed by other considerations. Figure 7 is not intended to reflect on earlier predictions made at various times. Rather, some of the same forces that have affected population growth have also influenced per capita usage. The figure brings out forcibly the revisions that must now be made of earlier predictions as a result of the inroads of the depression. As if sensing the onset of such a period, Wolman (6), in 1929, pointed out clearly that per capita consumption is greatly dependent on economic conditions. Other contributions on per capita consumption have been given by Metcalf (7), Whitman (8) and the writer (9).

To some observers, in viewing figures 5, 6, and 7 it may seem an anomaly that each is considered separately and on a slightly different basis. It is believed that careful study of the situation as it exists in the area will serve to show the fallacy in attempting to do otherwise. Actually the original data were prepared on as comparable a basis as possible and were discarded in favor of the figures shown. Certainly it can be argued that the method used in preparing figure 7 eliminates the error of estimating uses from the old town pump and the old oaken bucket in the earlier days.

As a general comment on the matter of per capita usage, it may be said that the increased use of meters, leakage surveys and other factors, many of which are independent of the effects of the depression, have brought about a decrement in this rate in the last two decades. Estimates for future rates as shown in figure 7, are based on careful observations of past and present conditions and while they may be upset in the future by any one of a number of unpredictable influences, there seems to be no present indication that the higher estimates, shown by some authorities will be reached.

WATER CONSUMPTION NEEDS

Ultimately all these predictions for the future have one goal in view—namely the estimate of total water consumption. The constant aim of all water departments is the proper correlation of supply and demand. The laws governing these two equalizing forces do not apply in the present case, however, in the same way as in most other business enterprises. One of the main reasons for this is that

there is often only one source of supply. In other words the retail department frequently has only one storehouse to draw upon whereas most commercial concerns have at least one alternate for an emergency.

Probably to a greater degree than in almost any other utility, water supply has become a human necessity that must not fail. Responsibility for insuring an adequate quantity and quality is a trust which those engaged in the pursuit accept when they enter such a service. This trust must be kept inviolate even though, in attempting to accomplish this end, mistakes are sometimes made.

In the late twenties it seemed reasonable to expect a rapidly mounting demand. Many officials prepared for an indicated future need and the resultant overexpanded capital structure has been the source of grave worries of most of these. The depression did not, however, single out water supplies for sacrifice upon the altar of overpreparedness. Furthermore some benefits have accrued to the group as a whole through the instrumentality of governmental support for truly self-liquidating projects. In fact, through the darkest days of the depression many men of courage utilized this advantage to the utmost and there will remain as an everlasting monument to them, the work performed under their direction at a time when prices were low and labor was willing.

The situation may now be carefully viewed in retrospect for the purpose of determining a future course. Former predictions of water needs have been shattered just as surely as those in other lines of endeavor. True, the loss was not nearly as great as in many business enterprises, but water supply, but its very nature, calls for extreme care and preparation and the burdens of lean years have been correspondingly greater. With the very definite pick-up in business, demand for water has increased but again there is a lag behind the average. While differences of opinion may exist as to just what the future holds in store, the financier who carefully says "I think there will be a ten percent increase in business next year" has in general no counterpart in the water works profession.

Nevertheless a start must be made somewhere and the writer has therefore attempted to correlate the factors of population, per capita consumption and total consumption to the end that some estimate may be made for the future. The result of the study is shown in figure 8. The most important feature brought out by this diagram is that the decrease in maximum yield, occasioned by a necessary

revision of yields following the dry period of 1929 to 1934, has almost equalled in per centage the corresponding loss in consumption during the depression.

Experiences in the past have indicated that in a conglomerate area such as the one under consideration, with inability for a complete interchange of water, shortages may occur even when the consumption is only about equal to the yield. Not only did shortages occur

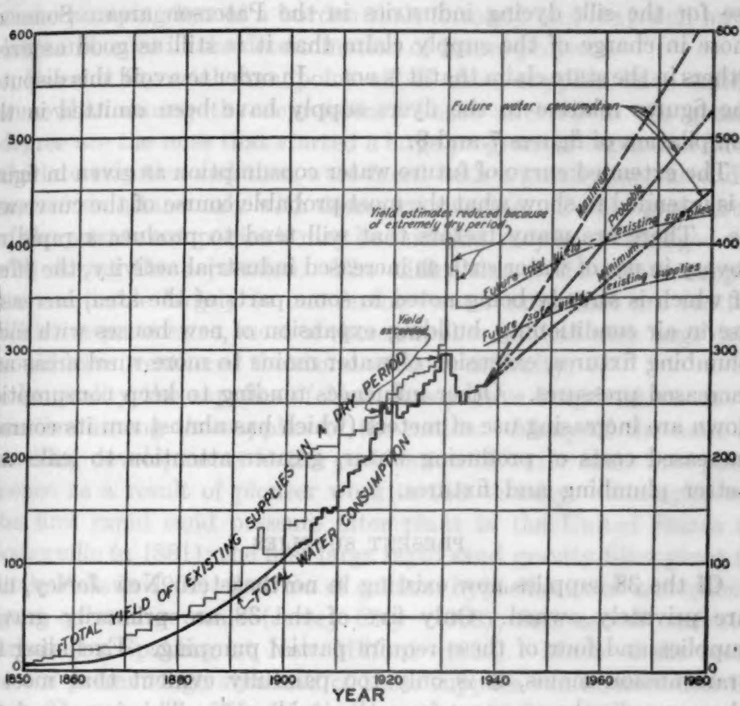


FIG. 8. WATER CONSUMPTION AND YIELD

in the area in 1918 and 1929 as indicated by the excess of consumption over yield but also in 1923 when there appears to have been a moderate excess of yield over consumption. This can and probably will happen again. Prudent planning dictates that in the future a certain margin of maximum yield over safe yield should be allowed. Extension of the yield and consumption curves under these conditions indicates that additional water must be available between 1943 and 1948 if adequate supplies are to be assured. It is possible that the

occurrence of a series of wet years between these dates might delay the necessity for water that long. Providing excuses for delays is not the attitude that should be taken by those holding a position of trust. One of the most controversial points in the consumption and yield figures of this area is the use of the Passaic River at Little Falls. Formerly, filtered water from this source supplied a large part of the metropolitan area. In 1932 this water was converted to industrial use for the silk dyeing industries in the Paterson area. Some of those in charge of the supply claim that it is still as good as ever. Others in the state claim that it is not. In order to avoid this dispute, the figures relative to the dyers supply have been omitted in the compilation of figures 7 and 8.

The extended curve of future water consumption as given in figure 8 is intended to show what the most probable course of the curve will be. There are many factors that will tend to produce a rapid recovery in use of water such as increased industrial activity, the effect of which is already being noted in some parts of the area, increased use in air conditioning, building expansion of new houses with more plumbing fixtures, extension of water mains to more rural areas and increased pressures. Other influences tending to keep consumption down are increasing use of meters (which has almost run its course), increased costs of producing water, greater attention to leaks and better plumbing and fixtures.

PRESENT SUPPLIES

Of the 38 supplies now existing in northeastern New Jersey, nine are privately owned. Only five of the 38 are primarily gravity supplies and four of these require partial pumping. Excluding the transmission mains, it is only too painfully evident that most of these supplies have grown from the inside out. This is not a drawback for an isolated community but in the area in question it means that the possibility of interchanging water between supplies is reduced to a minimum.

Pressures in this area are probably higher than the general average elsewhere. There is a constant trend toward increasing pressures and this factor must not be neglected in planning for the future. About 60 percent of the water consumed has a hydraulic gradient elevation of 230 or less and flows to an area with an elevation of 100 or less. A little more than 30 percent of the water is delivered at a gradient elevation of 400 to 230, to an area having an elevation of 100 to about 300, and

the balance of less than 10 percent is delivered to a high service zone with gradients up to nearly 700. Maintaining the constantly higher gradients that are being demanded will continue to increase the dependency on pumping. Modern pumps and motors have reached a high degree of efficiency and reliability and cannot be expected to improve greatly along those particular lines. However some decreases in cost of power may be forthcoming. All of this tends to make pumping less of a burden than formerly and may well have a large influence in the determination of future projects.

From a financial standpoint all of these supplies have suffered somewhat during the depression. Those affected to the greatest degree are the ones that started a large program of expansion during the late twenties and then were faced with a greatly increased debt service simultaneously with decreased revenue. To the great credit of the private companies it may be said that they have managed very well during the depression. The difficulties of the public supplies are ascribable largely to one factor—water rates that are too low. With adequate rates, most of those supplies saddled with large debts would have weathered the storm without difficulty.

In quality the supplies of New Jersey have long held an envied position among the supplies of the nation. Many of the most far reaching developments in the purification of water came into prominence as a result of pioneer work in this vicinity. Examples are: the first rapid sand pressure filter plant in the United States (at Somerville in 1881); the first large rapid sand gravity filter plant (at Little Falls in 1902); first use of calcium hypochlorite as a sterilizing agent on a large scale (Jersey City—1908); first use of activated carbon (by Spalding at New Milford—1930). Much of the credit for the present high standard of these supplies can be accorded the State Department of Health for its persistent efforts in the matter of quality.

These remarks are not contended to convey the idea that the supplies in the area are above reproach in respect to quality. On the contrary, the writer is one of the group which has always held the belief that all of the surface water in this district would be improved by filtration and that the consumers are entitled to such improved quality. At present about fifty percent of the total volume of water delivered in the area is unfiltered surface water. The late George Johnson stated that under such conditions many of the persons supplied were merely sitting on a keg of dynamite. Such an extreme

opinion hardly seems justified but the general viewpoint is well taken.

LESSONS OF THE PAST

Much of the preceding part of this paper is devoted to a presentation of the facts relative to the growth of the area under consideration. Other things being equal, water consumption increases under continued growth. Practically every one who has studied the problem believes that the population of the district will continue to increase. The present wide expansion of building activities is a visible testimony to bear out this belief.

All past reports on the subject indicate that population and industrial growth are prime factors in determining the need of new water supplies. It is true that not all of the predictions of growth have been accurately borne out but it is also true that some of the failures to carry out the proposals for new supplies have resulted in higher costs at a later date. The present writing is an attempt to view these earlier efforts in retrospect and to be so guided that the mistakes of the past will not be repeated in the future.

Two failures to meet the situation in former days seem to stand out prominently. The first was the failure to consummate the Lake Passaic proposal as outlined in the Geological Survey Report of 1905. While this scheme may have had some shortcomings in the later demands for quality, nevertheless it would have solved the water supply needs for a long time to come. The second was the negative vote by the electorate of the state in 1915 on the matter of acquiring the Wharton tract in south Jersey for the purpose of holding it as a future water reserve. The effect of the latter denial was perhaps the more far reaching of the two because it definitely prevented state control of water supplies at the time and this result has militated against practically all of the subsequent undertakings that have embodied partial or complete state supervision.

If no other argument were used, a brief study of table 2 would be sufficient to indicate that an abundance of reports and a lack of action have characterized the entire situation.

CONSTITUTED AGENCIES CONCERNED WITH WATER SUPPLIES

In order to clarify the powers of agencies having general and specific jurisdiction of water supplies in the metropolitan area, table 5 has been prepared. The agencies are arranged in the order of

their creation although it must be remembered that some of them were outgrowths from previous bodies. References have been made in the text to some of the past bodies and it is not considered a necessary part of this paper to enumerate all past entities. It might also be said that their numbers are legion if one takes into account all of the committees, associations, municipal delegations and other bodies that have worked on the problem of water supply.

At present there are two bodies that are creative per se. These are the North Jersey District Water Supply Commission and the

TABLE 5

Powers of Existing Bodies with Respect to Water Supplies

State Department of Health: basic law passed in 1899; has approval of plans for water treatment systems, approval of quality of supplies and supervision of their operation. Power to prosecute pollution of streams.

Board of Public Utility: 1911; fixes rates of all private water companies and requires an annual report of financial transactions and physical assets from all water systems, both public and private.

North Jersey District Water Supply Commission: 1916; constructing agency for joint municipal projects. Has constructed and now operates Wanaque supply for eight participating municipalities and their customers at wholesale.

Passaic Valley Water Commission: 1927; operates water supply system of the three Cities of Paterson, Passaic and Clifton and their customers, mainly at retail.

State Water Policy Commission: *1929; has approval of all diversion of water, stream control and encroachments and, collection of excess diversion tax.

* Covers largely same functions as formerly carried out by State Water Supply Commission from 1907 to 1915 and by Department of Conservation and Development from 1915 to 1929.

State Water Policy Commission. The first acts distinctly as the agent for municipalities banded together for a common water supply. The second is the protective and policy forming body. Because of many circumstances that need not be expounded upon at length, the trails of these two frequently have crossed. A condition of stalemate has recently brought them together in what most of those familiar with the situation believe to be the most constructive program advanced since the start of the depression.

Much of the controversy started when the 1922 report by Hazen was issued, see table 2. Objections came primarily from land

owners in the vicinity of the proposed Long Hill reservoir. In 1924 the North Jersey District Water Supply Commission made a study of the problem and advocated a reservoir at Chimney Rock. While many intermediate discussions and some reports ensued during the next few years, the question was not brought to a head until 1929 when the newly formed State Water Policy Commission advocated a high level supply, indicating three possible sites namely: Bunnvale, Vernoy and Ralston. The North Jersey District Water Supply Commission reporting for the cities of Bayonne, East Orange, Elizabeth and Newark again proposed the Chimney Rock plan in 1930. In 1931 the State Water Policy Commission reported definitely in favor of the Bunnvale project. The situation was still further complicated by the report of the Army engineers in 1932 favoring the Delaware River development with part of Long Hill site as a tentative local storage reservoir. Naturally all of this difference of opinion induced much acrimonious discussion. Fuel was added to the fire when the referendum of 1930 was approved by the voters for the issue of bonds to the extent of $7,000,000 for the purchase of water supply lands and later rescinded in 1933.

LEGAL AND OTHER ASPECTS

With the advent of R. F. C. and P.W.A. funds, came recognition of the possibility of obtaining government financing for a water supply which would be truly self-liquidating. Governor Moore's special message on water supply in February 1934 was the forerunner of efforts along this line. Shortly thereafter a bill was introduced in the legislature to combine some of the existing agencies into a Water Authority, clothing this body with many of the powers that have long been recognized as desirable and permitting borrowing money from the federal government. Opposition to this bill developed to some extent from the municipalities whom the bill was intended to help. The bill proposed taking over the Wanaque supply as a nucleus and placing the wholesale delivery of water from this source and future sources in the hands of one body.

In December 1934 the report of the State Water Policy Commission to the Governor again recommended centralization of control over water supply developments and bills were again introduced in the legislature. While some of the clauses that had received the greatest objections were omitted, the later bills were in many respects similar to the first. Peculiarly enough some of those most active in

sponsoring the 1935 bill had been ardent opponents of the 1934 bill. Bills of a somewhat similar nature but far less comprehensive in detail were introduced in 1936.

Realizing that the situation had reached an impasse, the North Jersey District Water Supply Commission and the State Water Policy Commission held a joint meeting in July 1936 and outlined a program for concerted action. As an outcome of this procedure, a series of companion bills known as Senate 156, 157, 158, 159 and 160 were introduced in 1937 by Senator Loizeaux. A brief summary of the purposes of the bills is given in table 6. Opposition to the bills has come principally from the Passaic Valley Water Commission and the

TABLE 6

Senate 156: Appropriates $5,000 as State's share of a W.P.A. survey of interconnection of water systems. Survey sponsored by State Water Policy Commission (with cooperation of North Jersey District Water Supply Commission.)

Senate 157: All private or industrial water diversions over 100,000 gallons per day must be approved by State Water Policy Commission.

Senate 158: Expands powers of State Water Policy Commission to select and purchase water supply sites, to require interconnection of water systems and to contract with the North Jersey District Water Supply Commission for construction and operation of water supplies. (This is the main bill. It would clear the way for joint action by the two Commissions.)

Senate 159: Appropriates $700,000 for use of State Water Policy Commission in acquiring dam sites.

Senate 160: Clarifies and defines powers of North Jersey District Water Supply Commission so as to eliminate overlapping powers with the State Water Policy Commission and pave way for construction of future supplies.

residents of Morris County. Both groups object on the grounds that the bills are confiscatory with respect to autonomous development of municipal water supplies and the latter group adds an objection to the possible damage to real estate development within the county if the Bunnvale project should be selected. No purpose would be served by enumerating here the various arguments pro and con. Rather it is sufficient to say at this writing that very likely another year will pass without enactment of any enabling legislation.

FUTURE TREND

Although the floods of 1936 have given an impetus to those interested in justifying the cost of a flood control program by joining

it with a water supply problem and thus bringing to the fore the Whippanong project for the Passaic River, many engineers are of the opinion that a development of this sort would not produce the most desirable type of supply. Proponents of the plan state that flood control, mosquito control and water supply can all be accomplished in one project, and that the total cost will be only half of that needed for an equivalent water supply elsewhere.

The Whippanong project embodies, among other things, the development of real estate immediately outside of a small marginal area needed for flood peaks and the definite use of the marginal areas for such temporary purposes as bridle paths. Suffice it to say that such practices are in general frowned upon by most sanitary engineers. Perhaps the best comment in regard to this plan can be found in Dr. Kummel's report of 1919 which states that flood control and water supply are not wholly integral problems.

On account of its interstate nature and the reaction of the victory of New York State in the suit regarding the Delaware River diversion rights, the Ramapo appears to be unlikely to be accorded a front place for further consideration. Thus the only intra-state stream left to be developed is the Raritan River. Contrary to most of the popular beliefs, the Bunnvale and Chimney Rock projects both propose the use of largely overlapping areas in the upland reaches of the Raritan River. Since the Bunnvale dam would be at a higher elevation, its available watershed area would be smaller and in order to obtain a yield comparable to that of Chimney Rock, it would be necessary to go to the west for the additional area. Thus the Bunnvale project proposes diverting water from the Munconetcong, a tributary of the Delaware, both by a direct diversion and by a canal to collect the overflow water from Lake Hopatcong. This last adjunct probably caused a greater storm of criticism than any other point, and opponents of the plan have consistently claimed that it would result in ruining Lake Hopatcong as a summer resort. Perhaps the best answer to this is that Greenwood Lake, on the Wanaque shed, has never enjoyed better water control than since the advent of the Wanaque supply. Furthermore, contrary to many unqualified opinions, careful studies show clearly that the storage in Greenwood Lake, even if it could be drawn down (which is unlikely) would add little to the yield of the Wanaque. The same would be even more true of Lake Hopatcong, which has far less storage capacity.

Much of the doubt concerning the geographical relationship of the projects may be dispelled by a brief study of figure 1.

COMPARISON OF PROJECTS

The first of the more recent estimates, regarding the two most discussed projects, was made by the State Water Policy Commission in 1929. This was of a preliminary nature and showed a total cost of $48,980,000 for Chimney Rock and $46,280,000 for Bunnvale. While in all fairness these estimates should be generally regarded as merely approximate, it would be well to draw attention to the fact that peak prices were used to arrive at these figures. Furthermore, the Bunnvale delivery elevation was taken at 385 in 1929 but was reduced, in 1931, to 370. Intake elevations were raised in the interim and the correspondingly greater head available was utilized to reduce the size and cost of the delivery aqueduct. Of far greater importance were the more detailed reports of 1930 and 1931 by the North Jersey District Water Supply Commission and the State Water Policy Commission respectively. Both of these reflected the falling prices and showed total costs materially less than those mentioned in the preceding paragraph. In order to clarify the conception as to these estimates, table 7 has been prepared. This shows a comparison of costs of the 1930 and 1931 tabulations of the two Commissions, as broken down by the writer. As far as is known, no table of this type has been published before. For the purpose of guiding the reader and at the same time presenting the problem impartially, the following remarks regarding these estimates are given:

Two very important items of difference between the basic plans of the two Commissions are filtration and delivery aqueducts. The State Water Policy Commission included filtration in all estimates and in 1931 showed costs for the Chimney Rock aqueduct only to a point opposite the so-called Stony Hill Reservoir for the purpose of comparing costs. Actually this reduced the cost of the Chimney Rock aqueduct about $8,000,000 but it is somewhat doubtful if the Bunnvale aqueduct could be laid to a central point for distribution as cheaply as the Chimney Rock aqueduct. The spread in cost would not be large however. The North Jersey District Water Supply Commission omitted filtration in the case of Chimney Rock.

The Chimney Rock supply would be an intermediate level supply delivering water at elevation 235 in Elizabeth and therefore closely

TABLE 7

Comparative Estimates of Cost

	Chimney Rock		Bunnvale	
	N.J.D.W.S.C. 1930	S.W.P.C. 1931	N.J.D.W.S.C. 1930	S.W.P.C. 1931
Construction Costs:				
Intake Storage	$380,000*	$120,000	$440,000	$54,000
Diversion Aqueducts	7,930,000	7,454,000	4,110,000	1,884,000
Main Dam	4,700,000	4,434,000	1,630,000	1,530,000
Appurtenances	1,950,000	2,726,000	5,230,000	5,551,000
Delivery Aqueduct	11,160,000	2,840,000	10,610,000	4,800,000
Equalizing Res'r			960,000	1,398,000
Filtration		5,370,000	2,760,000	5,640,000
Delaware R. Compensation				365,000
Total Construction Cost	$26,120,000	$22,944,000	$25,740,000	$21,222,000
Real Estate:				
Intake Storage	$100,000*	$36,000	$50,000*	$24,000
Diversion Aqueducts	630,000*	1,048,000	200,000*	232,000
Main Storage	4,250,000	4,860,000	7,130,000*	5,408,000
Delivery Aqueduct	480,000	222,000	750,000*	758,000
Equalizing Res'r			500,000*	520,000
Filtration		60,000	60,000*	60,000
Delaware R. Compensation				242,000
Total Real Estate	$5,460,000	$6,226,000	$8,690,000	$7,244,000
Water Rights	$500,000	$825,000	$1,170,000	$1,378,000
Engineering Legal & administration	7,580,000	7,449,000	7,570,000	7,461,000
Total Cost	$39,660,000	$37,494,000	$43,170,000†	$37,305,000
Yield M. G. D.	140	145	155	152
Cost per M. G. D.	$283,000	$258,000	$278,000	$245,000

* Approximated by breaking down original estimate.

† Filtered at Summit. Cost unfiltered to Elizabeth to compare with Chimney Rock = $44,700,000 or $288,000 per M. G. D.

comparable to Wanaque in respect to pressure. It may be combined later with a second stage high level development. The Bunnvale supply is essentially a high level development, not quite comparable with Newark's Pequannock supply in delivery elevation. To supply

the suburban areas would require considerable pumping in either case but obviously pumping would be more costly for Chimney Rock than Bunnvale. Assuming a final gradient difference of 135 feet between the two and a cost of 5 cents per M.G. raised per foot, the additional cost per M.G. for Chimney Rock would be $6.75. If 30 percent of Chimney Rock water had to be pumped this extra elevation, the capitalized cost per M.G.D. developed would be about $13,000 in favor of Bunnvale.

The Chimney Rock dam site is complicated by the existence of the quarry and the Bound Brook water Company, while the main reservoir area offers no particular obstacles. At Bunnvale the dam site is relatively uncomplicated but the reservoir requires the relocation of several miles of track of the Central Railroad of New Jersey. A steep grade is required to carry the railroad above reservoir level and the combined railroad and highway relocations account for over 50 percent of the total cost of the main reservoir structures. It seems possible that by the time construction of this source could be started, consideration of the abandonment of this trackage might be in order.

The bulk of the Chimney Rock catchment area is largely remote from the reservoir proper and requires the use of extensive diversion aqueducts capable of carrying a large part of the flood flows of the North Branch, South Branch, Black River, Rockaway Creek, Spruce Run and a few smaller streams, all tributaries of the Raritan River. The Bunnvale Reservoir is located directly on the South Branch and therefore has a much larger proportionate area directly tributary to the storage basin. The Bunnvale watershed coincides with a large part of Chimney Rock watershed in so far as South Branch and Black River are concerned and includes in addition Lake Hopatcong and the Musconetcong River, thus involving interstate waters. Bunnvale diversion aqueducts are relatively short but the transmission aqueduct is much longer than Chimney Rock.

Both projects are susceptible to partial development, which is a feature worthy of careful consideration under present financial conditions. In the final analysis it may be said that both are feasible from an engineering standpoint and it becomes a question therefore of determining which site can be agreed upon, consistent with consideration of the area to be served and the ultimate cost. The writer believes that filtration is definitely desirable in all cases and should be included in all estimates. Present day methods have

shown however, the filtration costs can be very much less than those given in table 7.

Before leaving this subject, reference should be made to the comparison of these two projects with existing ones and others that have been proposed. Present estimates suffer greatly by comparison with original costs of earlier supplies. If, however, the increase in prices is taken into consideration by applying a price index factor, a different aspect is obtained. Figure 9 has been prepared to show these features. No actual figures are given as it is felt that the purpose will be better served by simply presenting the diagrammatic answer. A very important item in comparing figure 9 with table 7 is that the yields shown in the latter are those estimated prior to the 1932 dry period. Figure 9 is based on present revised yields, and costs per M.G.D. are correspondingly affected.

OTHER PROJECTS

The Delaware River study of the Army engineers represents a vast amount of work and should be accorded its proper place. While many details are lacking, table 8 as abstracted from that report gives some idea of relative costs. The cost per M.G.D. developed is materially less than for any project wholly in New Jersey. It is important to note, however, that the relatively low cost is dependent on spending a large amount of capital funds for reservoirs, on getting coöperation of the three states or by handling the project by federal sources, and last but not least on the sale of power at costs that may be open to some question. At the present time there is no indication that all of these obstacles can be surmounted within a reasonable time. Attention should be drawn to the fact that if a Delaware River development in any form should be started after some other project in New Jersey, there may still be an opportunity to coördinate the two to some extent, but revised estimates would be required.

Recently conferences have been held between officials of Philadelphia and New Jersey indicating that a joint development of sources (tributary to the Delaware), in the Pocono mountains, might offer a reasonable solution. This suggestion has not, at the time of this writing, reached a point where facts or figures can be presented. Off hand there would seem to be just as many difficulties in a plan of this sort as in any of the others, even though they be of different nature. In 1899, Rudolph Hering, reporting to the City of Philadelphia, gave consideration to use of water from the tribu-

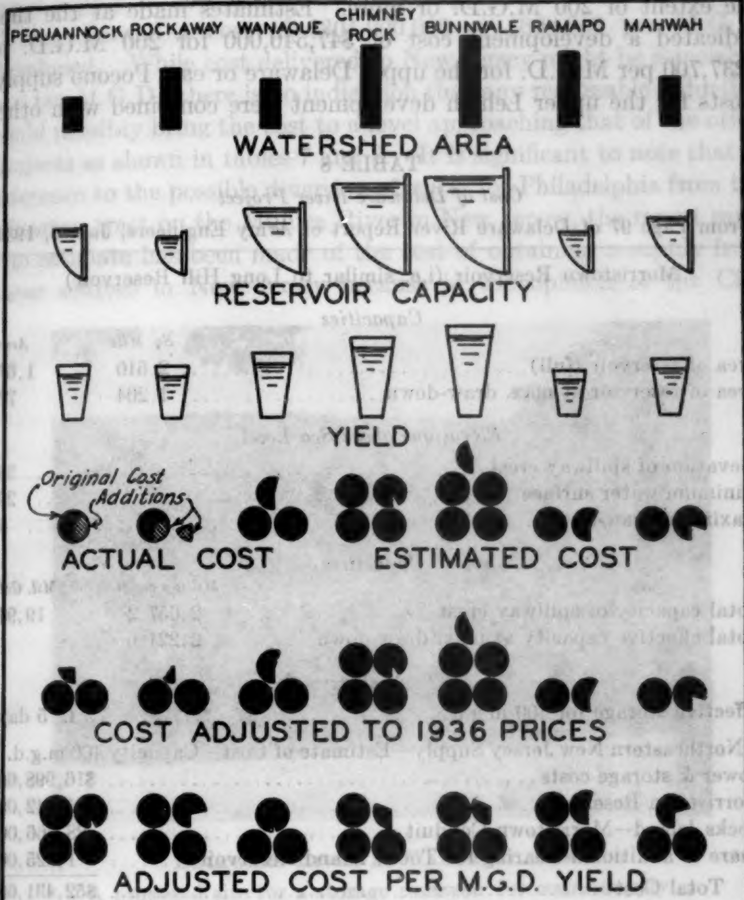


FIG. 9
COMPARISON OF WATER SUPPLIES

taries of the upper Delaware, running eastward from the Poconos, near the Water Gap, indicating that a supply of 200 M.G.D. could be obtained. Another alternate was the use of water from the tributaries of the Lehigh, running westward from the Poconos, to

the extent of 200 M.G.D. or more. Estimates made at the time indicated a development cost of $47,540,000 for 200 M.G.D. or $237,700 per M.G.D. for the upper Delaware or east Pocono supply. Costs for the upper Lehigh development were combined with other

TABLE 8

Cost of Delaware River Project

(From Page 97 of Delaware River Report of Army Engineers, Jan. 3, 1934)

Morristown Reservoir (i.e. similar to Long Hill Reservoir)

Capacities

	Sq. Mile	*Acres*
Area of reservoir (full)	2.610	1,670
Area of reservoir at max. draw-down	1.204	770

Elevations above Sea Level

Elevation of spillway crest	330
Minimum water surface	290
Maximum draw-down	40

Capacities

	Million cu. ft.	*Mil. Gals.*
Total capacity of spillway crest	2,657.2	19,900
Total effective capacity at max. draw-down	2,221.6	

Yields

Effective storage for 400 m.g.d	42.5 days

Northeastern New Jersey Supply—Estimate of Cost—Capacity 400 m.g.d.

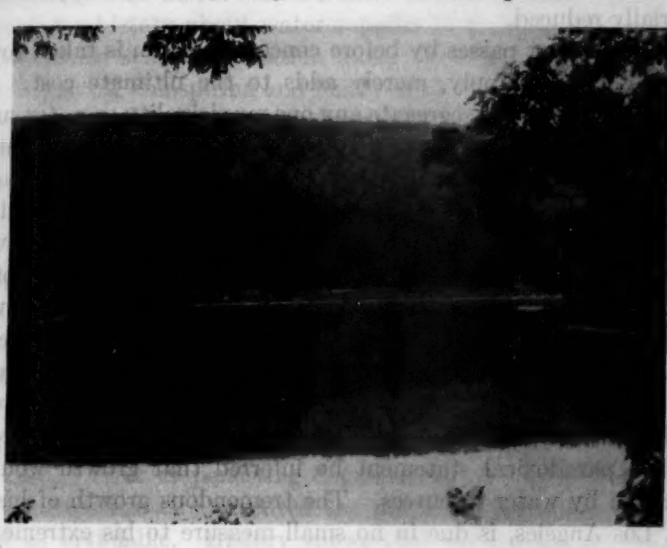
Power & storage costs	$16,998,600
Morristown Reservoir	5,642,000
Tocks Island—Morristown Conduit	28,766,000
Share of additional clearing for Tocks Island Reservoir	1,025,000
Total Cost	$52,431,600
Pro rata share of capitalized revenue from power combined project #2	$16,093,000
Net Cost	$36,337,700
Cost per million gallons daily ($36,337,700 ÷ 400)	$90,800

(Above table assumes joint use of Tocks Island reservoir by New Jersey and Philadelphia.)

costs but a segregation shows an approximate cost of $150,000 per M.G.D.

In 1924, George W. Fuller, Allen Hazen and J. Waldo Smith, reporting to Philadelphia, outlined some of the same projects, and

for a supply of 500 M.G.D. from the upper Delaware and Lehigh Rivers, showed a cost of $304,000,000 or $608,000 per M.G.D. developed. While cost delivered to New Jersey might be somewhat less per M.G.D., there is no indication that any reasonable reduction could possibly bring the cost to a level approaching that of the other projects as shown in tables 7 and 8. It is significant to note that in reference to the possible diversion of water for Philadelphia from the Wharton tract on the Mullica River in New Jersey, the report says, "no estimate has been made of the cost of obtaining a supply from these sources in New Jersey because in the opinion of the City



DELAWARE RIVER AT WALL-PACK BEND

A proposed site for a storage reservoir for water supply

Solicitor it is impracticable to give serious consideration to them owing to legal complications arising from their location in another state." This is very significant in view of the present proposal of an analogous situation.

FUTURE PROGRAM

Past experience has shown that objections to any proposal will be legion and that the only way for progressive action is by constant efforts to obtain a majority in favor of one plan or another. The coöperation of the two water commissions, which has been in progress for a little more than a year, has probably done more to bring about

about true appreciation of the problem and steps toward its solution than any other circumstances that have occurred in the last eight years. Definite progress has been made toward coöperative action on the very complex matter of inter-connection of mains. It has been the writer's privilege to carry out a major portion of the preliminary work along this line. The situation as found cannot be described as anything less than appalling to any waterworks engineer. For a relatively small sum of money, merely by installing suitable interconnections, many supplies can be augmented and the justifiable fear of the individual men operating each supply can be materially reduced.

Each year that passes by before concerted action is taken toward initiating a new supply, merely adds to the ultimate cost. It is admittedly difficult to segregate any one municipality or water supply and to say that it will go short of water at a certain time. Indications are that shortages will occur before the next major supply becomes available. The late Leonard E. Metcalf has indicated that water consumption is to quite a large extent dependent on water rates. The City of Denver, hemmed in on the east slope of the Rockies, has had to tunnel through the mountains for more water because the original supply would not sustain any material increase in population. The general situation was most adequately expressed by the late William Mulholland who said in respect to water supply: "If they wait until they have to have it they won't need it." By that paradoxical statement he inferred that growth would be controlled by water resources. The tremendous growth of his own City, Los Angeles, is due in no small measure to his extreme foresightedness in going long distances for water and assuring abundant quantities. Industries are quick to sense such a situation. Those in this area which were subjected to curtailment of use in 1929, when a shortage occurred in some parts of the area, have not forgotten that experience. Unquestionably this has reacted unfavorably. A repetition must be avoided in the future.

FINAL COMMENTS

Many volumes could be written without completely exhausting this subject. An attempt has been made herein to give an up to date outline of the more important facts bearing on the case, both historical and technical, and at the same time bring out certain viewpoints that have never before been made public.

Because of his connection with one of the Commissions so vitally interested, the writer has refrained from adding here a list of conclusions and recommendations, believing that such a procedure would further agitate the maelstrom of dissension and that many of such statements might be misconstrued or misrepresented. Rather, there are incorporated in the body of the report, certain viewpoints, reinforced and substantiated by figures and tables, that seem obvious. In most respects the reader is invited to draw his own conclusions.

Not long ago a man past middle age, acting under some form of subsidy, appeared at the writer's office and announced that he was composing a history about water supplies in the vicinity and would like to obtain some information along those lines. His questions were vague and uninspiring and finally in the dim hope of making an impression as to his sincerity, he drew out a map which he had traced "from some book in the library." The map was immediately recognized as one that appeared in a 375 page report on the subject of water supplies and a large part of the report was devoted to precisely the type of information that he desired. Brief as this paper has attempted to be in encompassing such a large problem, there is little chance of its being studied by such men as that. The hope is expressed, however, that some light may be shed upon this subject for the benefit of those who desire to read not only the printed lines but also between them.

Like men in all professions, some engineers at times fall into the very human error of persisting dogmatically in certain tenets long after progress has circumvented the particular fortress which they regard as inviolable. History shows that such cases are not permited to impede the flow of advancement beyond a reasonable period and history will repeat itself in the present case. Furthermore, it may be pointed out that the engineers have eliminated those plans which seem entirely unfeasible and have presented others which are feasible and at the same time adaptable to proper future expansion.

The fact persists that the main problem is now fully as much social, economical, political and legal as engineering. After the course has been decided by all the parties necessarily involved, the engineers can proceed to find the method of solution for the particular choice. What is mainly needed is permission or authorization for a definite course of action.

Finally there arise two very moot questions that must be answered soon if New Jersey is to maintain its present rank in the affairs of

the nation. These are first: Does the public realize the seriousness of the situation and if not how may this be brought home to them? and second: If the public does know this, or when they shall come to know it, how may steps best be taken to remedy the defects?

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SILICATES AS AIDS TO COAGULATION*

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The silica in natural waters has been found to give considerable aid to coagulation of water with aluminum sulfate. To a lesser extent, this is true for coagulation with the iron salts. In addition, it has been found that adding silica in a certain form to water causes the coagulation to be produced more rapidly than it otherwise would be produced. Also, the added silica produces larger flocculated particles which are not so easily broken up by agitation as are the coagulated particles where no silica is used. Formation of the larger particles produces more rapid settling of the coagulated matter in settling basins, and being tougher, it is removed more effectively by the filters.

When solutions are prepared from distilled water and an alkaline carbonate, such as calcium, magnesium, or sodium, the prepared water, as a rule, coagulates readily only within a narrow pH range. The addition of a very small amount of the prepared silica causes the synthetic water to be coagulated with aluminum sulfate under about the same condition of pH and alkalinity as natural waters. The use of larger amounts of the silica causes rapid coagulation of the synthetic water as well as more rapid coagulation of natural waters. Establishing the fact that the silica naturally in water aids coagulation is of technical interest, but finding that the addition of a certain form of silica to water gives additional aid to coagulation may be of importance in water purification.

There are many waters where difficulty is experienced at certain times in producing a satisfactory coagulation, and we have been unable to explain why this is the case. At present, it is not known if the cause is due to lack of silica in the water, though this is a possibility. Another possiility is that part or most of the silica which is present in water is not in a form that gives aid to coagulation. Experiments on treating such waters with small amounts of silica in

* Presented at the Buffalo convention June 8, 1937.

the proper form appears to overcome nearly all such difficulties. Probably it is too much to hope that this will be fully realized, but experiments so far conducted show that the addition of silica to water will be well worth its cost in at least a few filtration plants.

DISCOVERY THAT SILICA AIDS COAGULATION

Although much work has been done in years past on the coagulation of water with aluminum sulfate, and with the iron compounds, filtration chemists have realized that there was something about coagulation not fully understood. At least it was impossible from chemical analyses of water to tell whether it would coagulate easily or with difficulty. When the hyrogen ion concentration of water began to attract attention in water treatment about 1921, many thought that this explained the reason why good coagulation was obtained under some conditions and with difficulty under other conditions. The accumulation of considerable data on the relation of hydrogen ion concentration to coagulation has revealed that there is something other than hydrogen ion concentration affecting the coagulation.

This early work on the effect of hydrogen ion concentration showed that many waters coagulated without difficulty when the concentration was between pH of 5.5 and about 7.5, though there were some waters which did not respond so well to treatment when the pH was adjusted to what was thought to be the ideal figure. Knowledge of the hydrogen ion concentration at which a particular water coagulates best has aided materially in producing good results in many filtration plants.

To obtain additional information on coagulation, Peterson and Bartow (1) investigated the effect of certain salts on coagulation. Later, Black, Rice and Bartow (2) published more information on the coagulation of water. Their work was done largely with synthetic waters, that is, distilled water to which certain amounts of alkaline and neutral salts were added. The experiments showed for the prepared waters in which sodium hydroxide was used, that coagulation was produced in the shortest time at a pH close to 7.25 to 7.4. For sodium bicarbonate, the pH range for shortest time was somewhat wider. The addition of neutral salts such as calcium and sodium sulfate was found to extend the range to the acid side, depending upon the amount used. The amount of neutral salts required to produce considerable aid was high and much more than is

found in many water supplies. Application of the facts established by Bartow and his associates to the treatment of natural waters in filtration plants did not produce as much aid in the coagulation of water as was expected, and it was realized that there still was something else which influences the results.

Experiments at Chicago. The work of Bartow and his associates was repeated in the laboratory of the Chicago Experimental Filtration Plant. In general, their results were confirmed on prepared solutions. The optimum pH in our experiments for such solutions was between 7.1 and 7.2, which is slightly lower than found by these authors. Part of this difference may have been due to not going to extreme refinement in making pH tests, and also to the use of alkaline carbonates instead of the hydroxides. LaMotte color standards were used, and no attempt was made to have the indicator solution "isohydric," as was done by Black, Rice and Bartow. The results obtained on prepared solutions were so different from those on natural waters, it did not seem necessary to go to extreme refinement in determining the pH, for a slight difference in pH could not make such a variation in results. Calcium bicarbonate was added to rain water collected from the gutters of a building and gave results which varied considerably from solutions prepared with distilled water. The substances in solution in rain water collected under such conditions are very low, yet their is enough of something to aid coagulation. This indicated that the substances affecting the coagulation may be present in water in extremely small quantities.

Figure 1 gives typical curves of the relation between pH and time of stirring for water having a calcium carbonate alkalinity of 40, when 10 ppm. of aluminum sulfate are used. Where lines are shown broken, the curves were not established accurately, though they are approximately correct. The pH range for shortest time of stirring is narrower for lower alkalinities and wider for higher alkalinities. These results differ considerably from those obtained on natural waters, as is shown by the curves in figure 2 for Lake Michigan water treated with 7.5 ppm. of aluminum sulfate. This was close to the minimum amount of aluminum sulfate necessary to produce excellent coagulation. The alkalinity of the lake water was 120, and the pH was varied by adding CO_2 or lime. It will be noted that the pH range is very much wider than was obtained with the prepared solution. Lake Michigan water does not contain a large amount of neutral salts and the difference between the two waters did not seem to be

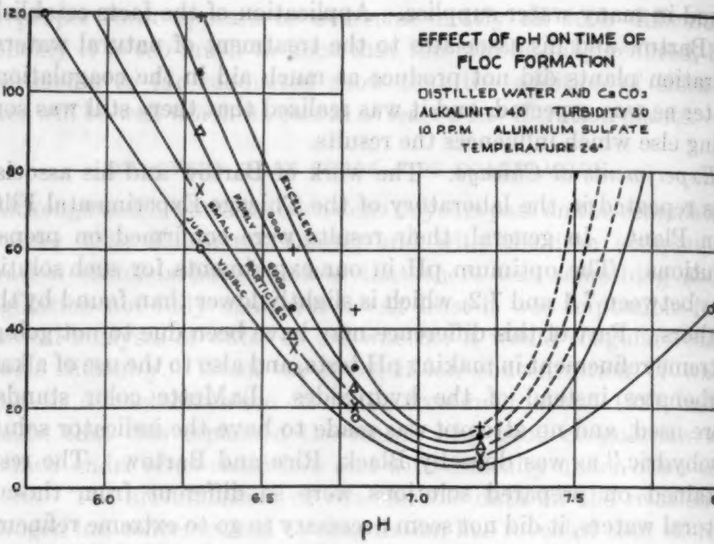
EFFECT OF pH ON TIME OF
FLOC FORMATION
DISTILLED WATER AND CaCO3
ALKALINITY 40 TURBIDITY 30
10 P.P.M. ALUMINUM SULFATE
TEMPERATURE 26°
TIME OF STIRRING IN MINUTES
120
100
80
60
40
20
0
6.0
6.5
7.0
7.5
8.0
pH
EXCELLENT
GOOD
FAIRLY GOOD
SMALL PARTICLES
JUST VISIBLE

FIG. 1

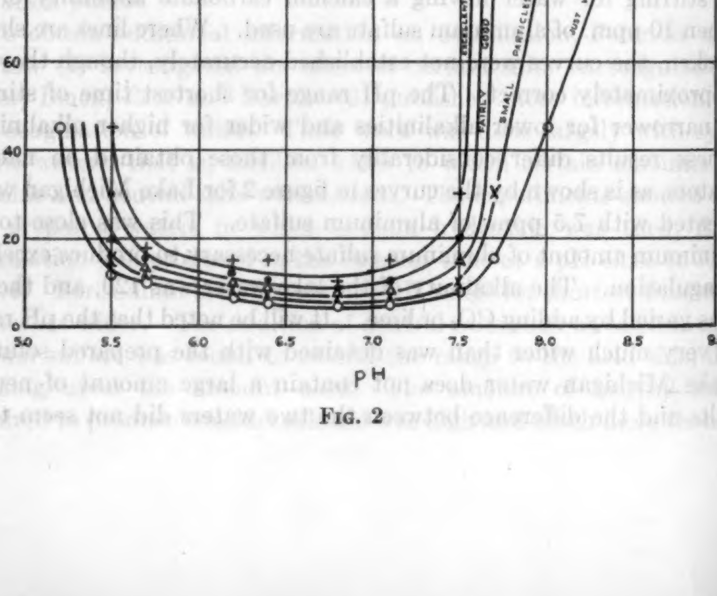
EFFECT OF pH ON TIME OF
FLOC FORMATION
LAKE MICHIGAN WATER USING
CO2 OR LIME TO VARY THE pH
7.5 P.P.M. ALUMINUM SULFATE
TURBIDITY 30 TEMPERATURE 25°C
TIME OF STIRRING IN MINUTES
120
100
80
60
40
20
0
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
pH
EXCELLENT
GOOD
FAIRLY
SMALL PARTICLES
JUST VISIBLE

FIG. 2

enough to produce such a wide variation. Experiments then were conducted on the lake water diluted with distilled water. Where the concentration of lake water was more than about 20 percent of the mixture the results were somewhat similar to those shown in figure 2, for the lake water without dilution. The lake water contains about 12 ppm. of sulfates as SO_4. The 20 percent mixture therefore gave less than 3 ppm. of SO_4. Tests on distilled water to which varying amounts of calcium sulfate were added indicated that such a small amount of sulfate had little affect upon the coagulation. This seemed to establish definitely that there was something in the water aiding the coagulation which heretofore had not been suspected of aiding.

A new series of tests then were started to try to find this unknown substance. Varying amounts of almost every substance likely to be present in water were tried. Fortunately the silica solution first prepared gave slight aid to coagulation, or silica probably would have been reported as giving no aid. Many silicate solutions prepared afterwards did not aid coagulation. The first silicate solution was prepared from an old sample of sodium silicate in which the alkali had become partially carbonated owing to a loose-fitting stopper. The silica in this solution happened to be in a form which gave a little aid to the coagulation, and indicated that silica may be the long sought-for substance. When new sodium silicate was tried, the results were discouraging, and gave the impression that it was not silica but possibly an impurity in the first solution that gave the aid. Remembering that the first material had been partially exposed to the air, a dilute solution of the fresh material was carbonated to the extent that most of the sodium was converted to sodium bicarbonate. Largely by luck, an equilibrium was produced which formed a silicate that gave considerable aid to coagulation. These results gave proof that silica was the substance in natural waters aiding coagulation. Chemical analysis of the rain water used showed that it contained a small amount of silica and accounted for it giving results different from distilled water. Using the molybdate test for SiO_2, rain water has been found to contain from 0.4 to 1.2 ppm. of SiO_2. Some of the work on the use of silica to aid coagulation already has been published (3).

FORM OF SILICATE

The compound of silicon which gives aid to coagulation is not known definitely, though it is believed to be a colloidal hydrous

silicon dioxide possessing a strong negative charge. Tests on sodium silicate solutions before and after addition of sulfuric acid indicate there may be rapid conversion of the soluble silicate to an insoluble form, if reliance can be placed in the molybdate test for soluble silica. Sodium silicate solutions having different alkalinities after preparation were tested for soluble silica by this method. The results of these tests are given in table 1. Small portions, after the addition of the acid, were diluted at definite intervals, to a concen-

TABLE 1

Soluble silica in sodium silicate solutions

1.5 per cent SiO_2 solutions diluted to concentrations of 3.0 ppm. of SiO_2 just before testing with molybdate.

AGE OF SOLUTION	PARTS PER MILLION OF SOLUBLE SiO_2 FOR VARIOUS ALKALINITIES OF ACID-TREATED SODIUM SILICATE SOLUTION						
	0	1030	1210	1420	1710	2020	Carbonated
No acid	2.85	2.85	2.85	2.85	2.85	2.85	2.85
1 min.	.32	.55	.60	.56	.50	.70	*.55
3 min.	.30	.40	.42	.38	.41	.48	.40
5 min.	.28	.26	.30	.32	.36	.44	.30
7.5 min.	.28	.22	.24	.26	.33	.40	.25
10 min.	.27	.19	.21	.23	.30	.38	.22
15 min.	.27	.16	.19	.20	.28	.35	.20
20 min.	.26	.15	.18	.18	.26	.32	.18
30 min.	.24	.14	.17	.17	.25	.30	.16
45 min.	.24	.13	.16	.16	.24	.28	.14
1 hr.	.23	.13	.16	.15	.22	.28	.13
2 hrs.	.23	.12	.15	.15	.20	.27	.12
4 hrs.	.22	.11	.12		.20		.10
24 hrs.	.20	.10	.11	.14	.20	.27	.09

* Time starts at the end of the carbonating period. Carbonating required 4.5 minutes.

tration of 3.0 ppm. of total SiO_2 and tested for soluble silica. A portion of the sodium silicate solution, before adding the sulfuric acid, also was diluted to contain 3.0 ppm. of SiO_2, and tested for soluble silica. The solution which was used gave 2.85 ppm. of SiO_2. This indicated that about 95 percent of the silica, before addition of the acid, reacted with the molybdate. The tests given in table 1 show that within a very short time much of the silica is converted to a form which does not react with molybdate. About

80 percent of the silica for the 1210 alkalinity solution was converted to this form within about one minute after the addition of the acid, and over 90 percent within a few minutes.

The procedure given in "Standard Methods for the Examination of Water and Sewage" (4) was used in making the molybdate test for silica. This is believed to give the soluble silica only, and indicates that the acid-treated sodium silicate solutions which aid coagulation contain very little soluble silica. It also gives proof that the silica which gives the aid is in the precipitated form. The precipitate very likely furnishes the framework to which the aluminum hydroxide precipitate adheres. At least this assumption seems justified by the results obtained.

EFFECT OF ACID-TREATED SODIUM SILICATE ON COAGULATION WITH ALUMINUM SULFATE

Method of Conducting Experiments. The laboratory experiments were conducted in one-liter beakers, stirred at a rate to impart a momentum of about 1 ft. per second to the water. The characteristics of the coagulation were divided into six classifications.

1. Just visible. Coagulated particles just detectable.
2. Small particles. The particles were still small, but large enough to be readily detectable.
3. Fairly good. Particles probably 0.3 to 0.5 mm. in size.
4. Good. The particles appeared to be about 0.5 to 0.8 mm. in size.
5. Excellent. Many of the coagulated particles appeared to be about 1.5 mm. in size with a large portion of them being at least 1.0 mm. in size.
6. Immense. When most of the coagulated matter was included in particles over 1.5 mm. in size.

The observations on the water had to be made quickly, and the classification may not be exactly as indicated in the outline. There were many cases where the exact time in which the coagulation reached a certain classification was in doubt. The times recorded therefore should be regarded as approximate only. Probably the greatest error likely to be made was classifying a coagulation under one heading when it should have been under the adjacent classifica-

tion, such as "fairly good" when it should have been classified "fine particles" or "good." Although such errors are possible, the results can not vary greatly from those given. The tests in table 2 show that the same appearance of coagulation was produced within about 5 minutes with the use of silica as was formed within 25 to 40 minutes without silica. Certainly this is a great increase in the flocculation rate. Had the turbidity of the water been high enough to require 30 to 40 ppm. of aluminum sulfate to coagulate the water properly, the difference would not have been so marked.

Effect on Coagulation Rate. The increase in coagulation rate resulting from the use of acid-treated sodium silicate is very marked

TABLE 2

Effect of varying the amount of silicate on time required to coagulate Lake Michigan water

10 ppm. aluminum sulfate. Turbidity 2.0. 3°C. Sodium Silicate Solution No. 37. Alkalinity 1010. Solution used 24 hours after preparation.

PPM. SiO_2	pH	Minutes stirring required to form coagulation					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	7.3	5	7.5	10	15	*40.0	
3.0	7.2	3	3.7	4.3	5	7.5	
6.0	7.2	2.5	3	3.7	4.3	5	7.5
9.0	7.2	2.5	3	3.7	4.3	5	7.5
15.0	7.2	3	3.5	4	4.5	5	7.5
18.0	7.3	4	5	5.8	6.7	7.5	10
22.5	7.3	17	20	25	27	30	40
27.0	7.3	(No visible coagulation)					

* The coagulated particles were not quite as large as those classified "excellent coagulation."

for some waters, particularly those which are not very turbid and do not require a large amount of the coagulant. The aid given to the coagulation for a highly turbid water may not be worth the cost, for such a large amount of coagulant is used there is rapid settling of the coagulated material as the water passes through the settling basins.

Table 2 shows typical tests on the Lake Michigan water for low turbidity, and table 3 shows typical tests for turbidity near 100. This water is ideal for showing spectacular results with the use of silica. The turbidity is low most of the time, and the pH after the

addition of the aluminum sulfate is usually about 7.3 to 7.5, which approaches the alkaline zone where aluminum sulfate does not produce good coagulation.

Effect upon Size of Coagulated Particles. The formation of coagulated particles the size classified as "excellent" in so short a time indicates that much larger particles will be produced by continuing the mixing or stirring. This is the case, though the maximum size particles are formed more rapidly with use of the silicate. Some increase in the size of coagulated particles for aluminum sulfate alone may be observed after 30 minutes mixing with Lake Michigan water,

TABLE 3

Effect of varying the amount of silicate on time required to coagulate Lake Michigan water

15 ppm. aluminum sulfate. Turbidity 105. 4°C. 1180 Alkalinity Sodium Silicate Solution. The solution was used 48 hours after preparation.

PPM. SiO_2	pH	Minutes stirring required to form coagulation						Turbidity after filtering
		Just visible	Small particles	Fairly good	Good	Excellent	Immense	
0.0	7.2	3	4.5	7.5	15			0.2
1.5	7.2	2	3	4	7.5			0.0
3.0	7.2	1	2	3	4	6		0.0
6.0	7.2	1	2	2.5	3	4	5	0.1
9.0	7.2	1	1.5	2	2.5	3	4	0.0
15.0	7.2	1	1.3	1.7	2	2.5	3	0.0
22.5	7.2	1	1.5	2	2.5	3	*4	2.0
30.0	7.3	1	2	4	6	8	*10	7.0
37.5	7.3	3	4	7.5	10	*12.5		15.0

* Coagulated particles were large, but the solution was not properly coagulated.

when treated with the minimum amount of coagulant necessary to produce excellent coagulation: whereas with the use of silica, the maximum size coagulated particles, even though they are much larger in size, are produced within 10 to 15 minutes.

The classification of "immense" coagulation was adopted after finding that silica aided in producing coagulated particles larger than were produced otherwise. One reason for adding another classification was to avoid reclassifying the tests made previously on coagulation. The particles were so much larger than those produced originally when the coagulation was classified "excellent," that it

would not have been a fair comparison merely to call these maximum size particles "excellent."

Flocculated particles as large as one-half inch across have been produced in the plant experiments, though the particles with similar treatment in the laboratory have been somewhat smaller. These larger floc particles occurred in the settling basin near the point

TABLE 4

Effect of silica on settling rate

Plant Experiments

DATE	TURBIDITY				PPM. SiO_2	PPM. ALUMINUM SULFATE
	Raw	Coagulated	1.5 hrs. settling	3.0 hrs. settling		
			No silica used			
1-5-37	4.0	4.5	4.0	2.8	0.0	8.1
1-7	2.0	2.5	2.4	2.0	0.0	8.1
2-3	4.2	4.0	4.0	4.0	0.0	8.7
3-2	1.6	1.0	1.0	.6	0.0	8.0
3-5	4.0	3.5	3.0	2.0	0.0	8.1
4-5	24.0	22.0	15.0	10.0	0.0	11.0
4-9	19.0	18.0	13.0	7.5	0.0	11.1
Average. .	8.4	7.9	6.1	4.1	0.0	9.0
			Water treated with silica			
1-5-37	4.0	4.0	.4	.4	3.3	8.0
1-7	2.0	2.5	.6	.4	3.0	8.1
2-4	3.2	3.0	1.5	.9	2.8	8.3
2-5	4.5	4.3	1.5	1.4	3.1	7.9
3-3	1.6	1.0	1.0	.3	2.8	8.1
4-6	20.0	20.0	5.0	4.0	3.1	11.0
4-7	18.0	10.0	2.0	1.6	2.9	11.1
4-8	10.0	9.0	3.0	1.6	2.8	11.1
Average. .	7.9	6.7	1.9	1.3	3.0	9.2

where the water entered, and were not so large in the mixing basin. They evidently were produced by two or more of the larger particles striking each other in the settling basin and remaining attached. Little force very likely would have been required to break them into several smaller particles. These large flocculated particles produce a very spectacular appearance in the settling basin because they are

so much larger than particles to which we were accustomed to observing. There, of course, were particles varying in size from small to large, but nearly all of the coagulated matter was included in particles much larger than are produced without the use of silica.

Production of the large flocculated particles materially increases the settling rate, as is shown in table 4. These data were taken from plant tests. The upper part of the table gives settling results being obtained just before or just after making a run using silica. The lower part shows the results when silica was used. With 3 hours settling in the plant settling basins, the turbidity of the settled water was less than one-third what it was when no silica was used. The turbidity with 1.5 hours settling of the silica treated water was less than one-half what it was for the water with no silica after settling 3 hours. This indicates that shorter periods of settling may be used, unless it is desired to lessen materially the amount of coagulated matter going to the filters. As the coagulation is tougher, there may not be a corresponding lengthening of the filter runs for a given settling time by use of silica. Its effect upon filtration is discussed in another paragraph.

Silica Not a Coagulating Agent. What has been said of the aid given coagulation with silica should not be construed as meaning that a lesser amount of the coagulant will be required for turbidity and color removal in places where the minimum amount is now being used. If the colloidal silica is negatively charged, it should not be expected to aid in lessening the amount of aluminum hydroxide or ferric hydroxide necessary to remove a certain turbidity or color in the water. So far as can be told, there is no effect upon the amount of aluminum sulfate necessary to coagulate water to the extent it will filter to a certain turbidity. Neither is there effect upon the amount of color which will be reduced by aluminum sulfate. This means that silica probably will not be economical in most of the highly turbid and highly colored waters, for the aid given probably will not be worth the cost. There are a number of filtration plants where more coagulant is being added than is necessary because good coagulation and good settling are not being produced. The treatment should enable the coagulant dosage in such instances to be reduced to the minimum. There are other places where the pH of the water is not within a range where the best coagulation is produced, and more coagulant is required. In such cases, the silica may enable the coagulant dosage to be reduced.

Amount of Silica to Use. The minimum amount of SiO_2 required to produce nearly maximum aid to coagulation is about 40 percent of the amount of aluminum sulfate used. There is some additional aid by increasing the amount over the 40 percent ratio, but the additional aid very likely would not be worth the cost. There is an upper limit, however, which is usually several times the minimum amount, where more silica will prevent good coagulation of the water. The reason for this is not known, unless the volume of the colloid is too great for the aluminum to cover properly. There may be two forms of silica in the acid-treated silicate solution, one of

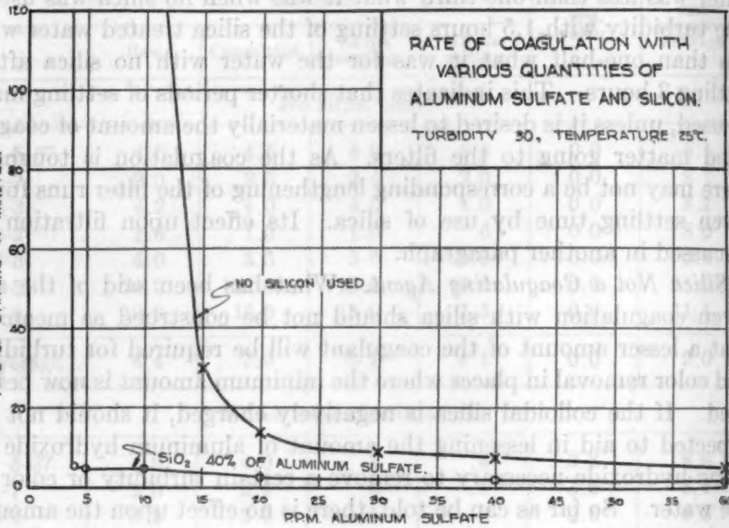

FIG. 3

which aids coagulation, and the other which retard coagulation. Figure 3 shows the effect of silica on the coagulation rate when the SiO_2 added was 40 percent of the aluminum sulfate. This is commercial aluminum sulfate containing about 17 percent aluminum oxide. For sodium silicate containing 30 percent SiO_2, about 1.2 times as much sodium silicate would be required as the amount of aluminum sulfate used.

There will probably be few conditions where it is desirable to add enough silica to give the maximum aid. One-half the amount will produce great aid to coagulation, and probably is close to the amount which will give the most economical results. This is about 20 per-

cent as much SiO_2 as the amount of aluminum sulfate used. Ten percent will give considerable aid to coagulation, and may be all that is necessary to produce the desired aid in many waters.

It has been stated that some of the silica naturally in water gives aid to the coagulation. This form of the silica may vary greatly in waters from various sources, and may vary considerably in water from the same source at different seasons of the year. The relation of silica in natural waters to its effect upon coagulation has not been studied as yet. This is going to be difficult to study, for it has been shown that the form of silica which aids coagulation is the precipitated or colloidal form which does not react with molybdate. The precipitated form may vary from small particles of crystalline silicon dioxide, which might be called pulverized sand, to colloidal hydrous silica. The colloidal hydrous form very likely is the form which aids coagulation most. Means of determining the various forms of silica in water are not known. A filter fine enough to remove most of the crystalline silica from water probably would remove some or most of the colloidal material.

At present, there seems to be no way of telling from chemical analysis whether or not it is desirable to use silica to aid the coagulation of a certain water. All that can be done is to try it to see if the aid given is worth the cost. In general, the amount used should not be more than one part of SiO_2 to 3 parts of aluminum sulfate, and usually it will be less.

PREPARATION OF SILICATE SOLUTIONS

Lack of knowledge of the form of silica which aids coagulation made progress in working out a suitable procedure for preparing solutions slow. A belief at first that it was a soluble form of silicate also caused some of the early experiments to be directed in the wrong direction. As stated, first efforts were to carbonate the alkali. Some of the solutions so prepared gave considerable aid to coagulation, yet some of them offered little or no aid. Once a suitable solution was prepared by using carbon dioxide, there seemed to be no way of telling by tests how to reproduce such a solution. The pH changed gradually and could not be used as a guide. Finally experiments with carbonated solutions were abandoned temporarily, believing that greater progress could be made by using a strong acid. The proportion of the alkali neutralized by a strong acid such as sulfuric can be determined readily by simple tests.

Use of Sulfuric Acid. The method of preparing silicate solutions by treatment of sodium silicate with sulfuric acid consists of diluting 41° to 42° Baume sodium silicate having a high silicon ratio to about 1.5 percent SiO_2, then nearly neutralizing the alkali with sulfuric acid. Some variation in the silica concentration from that given may be made, but most of the work done so far had been with this concentration, after addition of the sulfuric acid. The sulfuric acid is diluted with water from 66° Baume to a solution containing about 20 to 40 percent acid. The acid solution is added to the sodium silicate solution while being stirred until the alkalinity of the solution is between 1100 and 1300, and preferably about 1200 with the particular material used. The alkalinity test is made in the same manner as this test is made on water.

The procedure for preparing solutions to be used on a plant scale is to take small portions of the commercial sodium silicate and the sulfuric acid and make trial tests until the exact ratio of acid to sodium silicate is determined. With knowledge of the approximate normality of the acid, and the $Na_2O - SiO_2$ ratio, the approximate amount of acid to use may be determined by calculation. Slightly less acid than that necessarily to combine with all of the sodium is required.

In the preparation of solutions to be use in the Experimental Plant, 320-gallon batches of the solutions were made at a time. Forty-seven pounds of 42° Baume sodium silicate, containing 29 to 30 percent SiO_2, were added to enough water to make a solution slightly stronger than 5 percent of the sodium silicate, or 1.5 percent SiO_2. The 66° Baume sulfuric acid was diluted in the ratio of exactly one volume of acid and four volumes of water, adding the acid to the water. (Caution: Do not add the water to the Acid.) To mix the silicate and acid, the agitators in the solution tanks were started, and the acid solution added to the sodium silicate solution until nearly the computed amount was used. As soon as thoroughly mixed, the agitators were stopped, a small sample taken, and the alkalinity of the solution determined. Usually it was slightly more alkaline than desired. The additional amount of acid to use then could be approximated closely. A second alkalinity test was made, and if the solution was not approximately 1200 alkalinity, more acid or a little sodium silicate was added. Usually about 7.7 liters of 20 percent (by volume) acid were required for the 47 pounds of sodium silicate. Approximately 7.5 liters were added at first, then the

additional amount needed was added after making an alkalinity test. It is better to use a slightly lesser amount of acid than computed, and add the additional amount after testing the solution rather than to have to add a little sodium silicate. Usually if the alkalinity of the solution is between 1150 and 1250, no additional adjustment need be made.

The solution at the end of the addition of the acid solution contained about 1.5 percent of SiO_2. It was allowed to stand one to two hours, then diluted to the 320-gallon mark on the tank. This produced a solution containing approximately 0.6 percent SiO_2, or slightly more than 2 percent sodium silicate. The solution then was ready to use, and was fed into the water being treated through an orifice. Another tank was prepared several hours before the one in use ran out. The amount of SiO_2 to add to the water is discussed in another paragraph. The silicate solution should be added long enough in advance of the coagulant to be thoroughly mixed with the water.

EFFECT OF ALKALINITY OF SILICATE SOLUTION

Some thought has been given to the best means of testing the silicate solutions and to a term most suitable for designating the equilibrium of the acid-treated sodium silicate solutions. Bearing in mind that the tests, in many instances, will be made by persons not highly trained in chemistry, it was believed best to use a method likely to be familiar to such employes. The alkalinity test on water is frequently made by persons other than trained chemists, so it was thought best to use a similar test on the acid-treated sodium silicate solutions and express the results in the same terms used for alkalinity tests on water. As the alkalinity is high, usually only 10 cc. of the solution are used in making the test. A 10 cc. portion is diluted to 50 cc. with distilled water, two or three drops of methyl orange solution added, and the solution titrated with N/50 H_2SO_4 until there is a slight change towards pink color. Multiplying the cubic centimeters of acid used by 100 gives the alkalinity.

Only one concentration of silica solution so far has been studied extensively, and that is 1.5 percent SiO_2. A few of the early tests indicated that a 0.3 percent solution did not become very active, and that a 3.0 percent solution formed a jelly too readily for practical uses, so the 1.5 percent SiO_2 solution was decided upon for the early tests. This may not be the concentration which produces the

TABLE 5

Effect of varying the alkalinity of silicate solutions on time required to form coagulation

10 ppm. aluminum sulfate

PPM. SiO_2	ALKALINITY SILICATE SOLUTION	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	0	7.5	12.5	17	25		
0.0	690	5	7.5	13	20	35	
0.0	910	7.5	11	15	25		
0.0	1010	5	7.5	10	15		
0.0	1100	7.5	10	15	25		
0.0	1260	5	10	14	25	40	
0.0	1400	5	7.5	10	15		
0.0	1710	5	7.5	10	25		
0.0	2020	6	10	15	25		
1.5	0	50	60	75	90		
1.5	690	5	7.5	13	20	30	
1.5	910	6	7.5	10	12.5	15	
1.5	1100	6	7.5	10	12.5	15	
1.5	1260	4	5	7	10	12.5	
1.5	1400	3	5	7.5	10		
1.5	1710	5	7	9	12.5		
1.5	2020	6	9	12	20		
3.0	0	(No visible coagulation within 90 minutes)					
3.0	690	3	7.5	10	12	15	
3.0	910	5	6.2	7.5	9	12	
3.0	1010	3	3.7	4.3	5	7.5	
3.0	1100	5	5.8	6.7	7.5	10	
3.0	1400	3	4	5	7	10	15
3.0	1710	3	5	6.3	7.5	20	
3.0	2020	3	5	7	9	20	
4.5	0	(No visible coagulation within 90 minutes)					
4.5	690	3	5	7.5	8.7	10	
4.5	910	3	5	6.2	7.5	9	12.5
4.5	1260	3	3.7	4.3	5	7	9
4.5	1400	3	5	6.3	7.5	10	
4.5	1710	3	5	6	7	10	30
4.5	2020	7	9	11	13	15	

TABLE 5—*Concluded*

PPM. SiO_2	ALKALINITY SILICATE SOLUTION	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
6.0	0	(No visible coagulation within 90 minutes)					
6.0	690	3	5	5.8	6.7	7.5	
6.0	910	3	3.7	4.3	5	7	10
6.0	1010	2.5	3	3.7	4.3	5	7.5
6.0	1100	4	4.5	5	6	7	10
6.0	1260	3	3.5	4	4.5	5	7.5
6.0	1400	3	4	5	7	12.5	
6.0	1710	3	5	5.8	6.6	7.5	15
6.0	2020	7.5	10	11	12.5	15	
9.0	0	(No visible coagulation within 90 minutes)					
9.0	690	3	4	5	5.8	6.7	7.5
9.0	910	3	3.7	4.3	5	6	7.5
9.0	1010	2.5	3	3.7	4.3	5	7.5
9.0	1100	3	3.5	4	4.5	5	7.5
9.0	1260	3.5	4.2	5	5.8	6.7	7.5
9.0	1710	5	7.5	8.7	10	11.2	12.5
9.0	2020	20	(Not well coagulated)				

most active silica, but as it gave good results, the matter of varying the strength to determine the most suitable concentration has been deferred for tests which now seem more important.

The statement has been made that the range of alkalinity for the acid-treated solution may be from about 1000 to 1400. It is possible, to use a slightly lower alkalinity solution if the solution is diluted, just before it starts to form a jelly, to a concentration which will not form a jelly. The great difficulty is to know how soon the jelly will form. The silica, in any solution which will form a jelly, appears to be in the active state before the jelly forms—being most active probably at a certain time before the formation of the jelly. Solutions having an alkalinity over 1400 and less than 2000 usually give some aid to coagulation, but the useful effect decreases as the alkalinity increases over about 1350. Solutions having alkalinities over 2000 to 2500 may have a retarding instead of an aiding effect on the coagulation—the retarding effect increasing as the alkalinity increases. The alkalinities refer to the sodium silicate solutions treated with sulfuric acid, and also to solutions prepared by diluting 42° Baume sodium silicate. The silicate should have a high SiO_2

ratio and contain 29 to 30 percent SiO_2. The SiO_2 in the diluted solution is about 1.5 percent.

Table 5 gives tests made on the Lake Michigan water with various alkalinity sodium silicate solutions. These tests were made at various times, at various temperatures, and at various turbidities. This is why some of the results may appear to be out of line of the general trend. A retarding effect is produced with a solution made

TABLE 6

Effect of untreated sodium silicate on coagulation

10 ppm. aluminum sulfate. Turbidity 5 to 8. 17° to 25°C.

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION				
		Just visible	Small particles	Fairly good	Good	Excellent
Synthetic water containing 20 ppm. calcium carbonate						
0.0	6.2	90	120			
1.0	6.2	100	110	120	150	180
2.5	6.2	7.5	10	12.5	15	30
3.0	6.2	4	5	6.2	7.5	10
6.0	6.3	7.5	10	12.5	15	
6.0	6.3	120				
9.0	6.4	(No visible coagulation in 2 hours)				
Lake Michigan water, alkalinity 120						
0.0	7.3	7.5	10	15	25	
1.5	7.4	10	12	15	25	
3.0	7.4	11	13	17	25	
4.5	7.5	12.5	17	25	*40	
7.5	7.6	25	30	35	*60	
9.0	7.6	30	38	*50		

* The coagulated particles were large for the classification, but the water was not well coagulated.

slightly acid with sulfuric acid. A 1.5 percent SiO_2 solution having an alkalinity of 700 will form a jelly within 30 to 60 minutes unless diluted to about 0.6 per cent or less within this time. Such a low alkalinity solution after dilution remains fairly active for some time.

Essential to Treat Sodium Silicate Solution. Attempts to use the sodium silicate solution without treating with an acid have not been successful. When calcium carbonate is added to distilled water

to produce an alkalinity of about 20 to 30, the addition of a small amount of untreated sodium silicate aids the coagulation but large amounts retard it. Table 6 gives typical tests using untreated sodium silicate in synthetic waters and in Lake Michigan water. It is interesting to note that when about 2 to 6 ppm. of SiO_2 are used in the synthetic water, there is considerable shortening of the time necessary to produce coagulation at a pH of about 6.1 to 6.4. Figure 1 indicates that to produce excellent coagulation in synthetic waters at this pH without the use of silica, a long period of stirring is required.

The application of small amounts of untreated sodium silicate to the Lake Michigan water not only does not aid coagulation but retards it when the concentration is over about 3.0 ppm. SiO_2. It is difficult to explain why 3 ppm. of SiO_2 aids in coagulating the synthetic water and will not aid in coagulating the lake water. The synthetic water had a much lower pH than the lake water, and this may be partly the reason. There is the possibility that part of the silica of the sodium silicate is converted to the active form after addition to the synthetic water. In the tests given in table 6 the sodium silicate was added about 5 minutes in advance of the aluminum sulfate. Enough experimental work has not been done as yet to give reason for some of the factors revealed by these tests.

EFFECT OF VARYING THE pH OF THE WATER

Effect of Increasing the pH. Most of the tests so far given have been at pH values between 6.0 and 8.0. For prepared solutions, there is indication that silica does not give very much aid to coagulation with aluminum sulfate when the pH is high. This does not apply to the Lake Michigan water. When the pH of the lake water is increased by adding lime, there is a slight lengthening of the time required to form an excellent coagulation at pH between 7.6 and about 8.8 though not enough to be of much consequence. When the pH is higher or lower than these figures the coagulation is formed very rapidly.

The experiments on the lake water are interesting in that excellent coagulation may be produced when silica is used at any pH between 5.5 and 10.5. In fact, there may be good coagulation at a still higher pH, but precipitation of magnesium hydroxide above about 10.0 pH makes it impossible to tell whether the coagulation is produced by the aluminum sulfate or magnesium. Probably both aid in

TABLE 7

Effect of varying the pH and amount of silicate on time required to coagulate Lake Michigan water

10 ppm. aluminum sulfate. Turbidity 20 to 38. 12° to 20°C. Lime used to increase the pH, and CO_2 to decrease it. 1210 Alkalinity sodium silicate solution, and used 1 to 2 days after preparation.

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	5.5	7.5	20	30	50		
0.0	6.5	5	7.5	12.5	20		
0.0	7.0	5	6.2	7.5	20		
0.0	7.6	6	10	12.5	25		
0.0	8.5	12.5	30				
0.0	8.7	7.5	40				
0.0	9.4	2.5	3	4	5	7.5	12.5
1.5	5.5	5	7.5	10	12.5	20	
1.5	6.5	3	4	5	7.5	10	
1.5	7.0	4	5	6.2	7.5	12.5	
1.5	7.6	6	7.5	8.7	10	12.5	
1.5	8.5	7.5	10	12.5	15	30	
1.5	8.7	5	7.5	10	15	25	
1.5	9.4	2	2.5	3	4	5	10
3.0	5.5	4	5	6.2	7.5	10	20
3.0	6.5	2.5	3	4	5	7.5	12.5
3.0	7.0	3	4	5	6.3	7.5	12.5
3.0	7.6	5	5.8	6.6	7.5	10	12.5
3.0	8.5	6	7.5	8.7	10	12	20
3.0	8.7	5	6.2	7.5	8.7	10	20
3.0	9.4	1.5	2	2.5	3	4	5
4.5	5.5	3	4	7.5	8.7	10	15
4.5	6.5	2.5	3	3.7	4.3	5	7.5
4.5	7.0	2.5	3	3.7	4.3	5	7.5
4.5	7.6	5	6.2	7.5	8.7	10	12.5
4.5	8.5	5	6.2	7.5	8.7	10	12.5
4.5	8.7	5	5.8	6.3	7.5	10	12.5
4.5	9.4	1.5	2	2.5	3	4	5
6.0	5.5	3	3.5	4	4.5	7	9
6.0	6.5	2.5	3	3.7	4.3	5	7.5
6.0	7.0	3	3.7	4.3	5	6.2	7.5
6.0	7.6	5	6.2	7.5	8.7	10	12.5
6.0	8.5	5	5.8	6.6	7.5	8.7	10
6.0	8.7	3	4	5	7	10	12.5
6.0	9.4	1	1.5	2	2.5	3	5

TABLE 7—*Concluded*

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
9.0	5.5	2	2.6	3.2	3.8	4.5	6
9.0	7.7	8	10	10.8	11.6	12.5	15
9.0	8.5	5	5.6	6.2	6.9	7.5	10
9.0	8.7	3	4	5	6.2	7.5	10
9.0	9.4	1.0	1.4	1.8	2.2	2.6	3

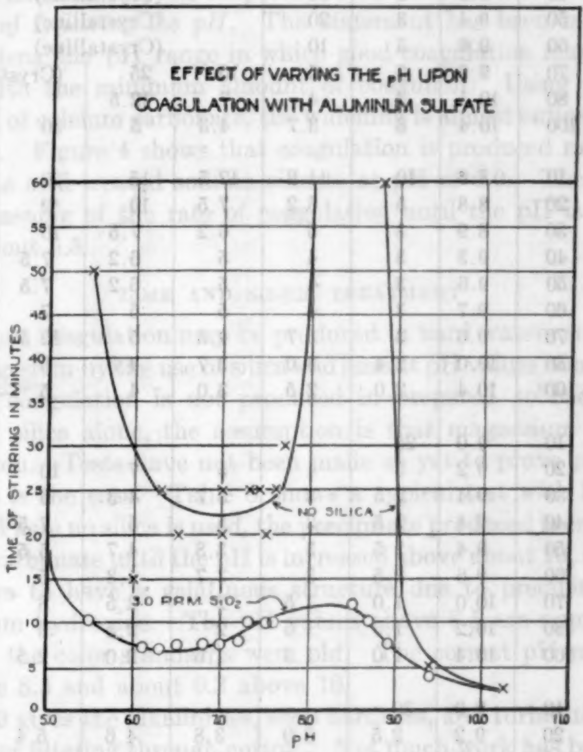

FIG. 4

forming the coagulation. The lake water contains about 10 ppm. of magnesium (Mg.). When aluminum sulfate is used without silica there is a zone between pH of about 7.8 to 9.5 where good coagulation

TABLE 8

Coagulation of Lake Michigan water with lime and silica

1200 alkalinity sodium silicate solution, used 1 to 3 days after preparation. Turbidity 6 to 18. 14°C.

PPM. SiO_2	PPM. LIME	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
			Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	10	8.7	15		(Slight crystalline precipitate)			
0.0	20	9.0	10	25		(Crystalline)		
0.0	30	9.1	7.5	12.5		(Crystalline)		
0.0	40	9.3	5	30		(Crystalline)		
0.0	50	9.4	3	20		(Crystalline)		
0.0	60	9.8	3	10		(Crystalline)		
0.0	70	9.9	3	5	10	25	(Crystalline)	
0.0	80	10.1	3	4	7	12.5		
0.0	100	10.4	3	3.7	4.3	5	30	
3.0	10	8.6	10	11.2	12.5	15	20	30
3.0	20	8.8	5	6.2	7.5	10	12	15
3.0	30	8.9	3	5	6.2	7.5	10	12.5
3.0	40	9.3	3	4	5	6.2	7.5	20
3.0	50	9.6	3	4	5	6.2	7.5	15
3.0	60	9.7	3	4	5	6	7	10
3.0	70	9.6	3	3.7	4.3	5	12.5	
3.0	80	10.0	2.4	3.0	3.7	4.3	5	
3.0	100	10.4	2.0	2.5	3.0	4	5	10
6.0	10	9.0	25					
6.0	20	9.2	3	4	5	7	10	12.5
6.0	30	9.4	2.5	3	3.7	4.3	5	10
6.0	40	9.4	2.5	3	5	5	7.5	
6.0	50	9.4	2.5	3	3.8	4.7	5.5	
6.0	60	9.6	2.5	3	3.7	4.3	5	7.5
6.0	70	10.0	1.0	1.5	2	2.5	3	7.5
6.0	80	10.2	1.0	1.5	2	2.5	3	5
6.0	100	10.4	1.0	1.3	1.6	2.0	2.5	3
9.0	10	9.0	30					
9.0	20	9.2	2.5	3.0	3.8	4.6	5.4	30
9.0	30	9.3	2.0	2.5	3.0	4	5	6
9.0	40	9.4	2.0	2.5	3.0	4	5	6
9.0	50	9.6	1.5	2.0	2.5	3	4	5
9.0	60	9.8	1.5	2.0	2.5	3	4	5
9.0	70	9.8	1.0	1.5	2.0	2.5	3	3.5
9.0	80	10.2	1.0	1.4	1.8	2.2	2.6	3
9.0	90	10.4	1.0	1.4	1.8	2.2	2.6	3

is not obtained, unless the amount of aluminum sulfate used is greatly increased over that necessary to produce excellent coagulation at lower or higher pH values. Silica, therefore, makes it possible to coagulate Lake Michigan water at any pH desired above about 5.5.

This should not be construed as meaning that silica will give the same aid to coagulation in the high alkaline ranges for all waters. There is some evidence that the magnesium in the Lake Michigan water, which is believed to be responsible, gives aid at a much lower pH than it does when alum alone is used. This will be discussed more fully in another paragraph. Table 7 and the curves in figure 4 show the effect of varying the pH.

Effect of Lowering the pH. The statement has been made that silica widens the pH range in which good coagulation may be produced with the minimum amount of coagulant. Using prepared solutions of calcium carbonate, the widening is almost entirely on the acid side. Figure 4 shows that coagulation is produced rapidly by use of the acid-treated sodium silicate at pH of 6.0. There is not much lessening of the rate of coagulation until the pH is reduced below about 5.5.

LIME AND SILICA TREATMENT

Excellent coagulation may be produced in hard waters containing some magesium by the use of silica and lime at pH values above about 9.0. As coagulation is not produced in prepared solutions with lime and silica alone, the assumption is that magnesium aids the coagulation. Tests have not been made as yet to prove positively that this is the case. Table 8 shows a typical test with lime and silica. Where no silica is used, the precipitate produced is crystalline calcium carbonate until the pH is increased above about 10, and then it appears to have a gelatinous structure due to precipitation of magnesium hydroxide. The pH values above 8.5 are approximate only, for the color standards were old. The correct pH may vary 0.1 above 8.5 and about 0.3 above 10.

Table 9 gives the alkalinities, soap hardness, and turbidities of the water after filtering through cotton. Not much work has been done on this method of treatment, though there are indications for some waters that the coagulant may be dispensed with altogether.

EFFECT OF THE AGE OF THE SILICATE SOLUTION ON COAGULATION

After treating the sodium silicate with acid to the desired alkalinity, a short time is required for the silica to change to the form

TABLE 9

Lake Michigan water treated with lime and silica

Solutions stirred 30 minutes, then filtered through cotton. Turbidity raw water—6 to 18.

PPM. SiO_2	PPM. LIME	pH DURING STIRRING	ALKALINITY Phenol-phthalein	ALKALINITY Methyl orange	SOAP HARDNESS	TURBIDITY	pH
0.0	10	8.7	18	136	108	3.8	8.9
0.0	20	9.0	32	142	92	2.0	9.0
0.0	30	9.1	18	104	60	9.0	8.6
0.0	40	9.3	16	78	62	12.0	9.1
0.0	50	9.4	18	68	40	10.0	9.3
0.0	60	9.8	24	60	32	7.0	9.6
0.0	70	9.9	30	62	60	0.0	
0.0	80	10.1	40	66	56	0.0	
0.0	100	10.4	58	78	46	0.0	
3.0	10	8.6	22	126	104	0.3	8.8
3.0	20	8.8	24	124	90	5.0	9.0
3.0	30	8.9	22	112	78	0.6	9.2
3.0	40	9.3	24	86	68	0.0	9.2
3.0	50	9.6	28	74	60	0.0	9.4
3.0	60	9.7	28	68	48	0.0	9.7
3.0	70	9.6	34	66	52	0.0	
3.0	80	10.0	40	68	44	0.0	
3.0	100	10.4	58	80	40	0.0	
6.0	10	9.0	22	132	136	2.5	9.0
6.0	20	9.2	22	122	124	2.0	9.0
6.0	30	9.4	20	96	108	0.6	9.1
6.0	40	9.4	20	88	90	0.5	9.1
6.0	50	9.4	22	70	72	0.2	9.3
6.0	60	9.6	24	66	56	0.5	9.6
6.0	70	10.0	32	64	42	0.0	9.8
6.0	80	10.2	44	66	35	0.0	10.0
6.0	100	10.4	58	76	38	0.0	10.2
9.0	10	9.0	22	128	134	6.0	8.9
9.0	20	9.2	22	112	128	1.4	9.0
9.0	30	9.3	20	92	112	.2	9.1
9.0	40	9.4	20	80	90	.4	9.2
9.0	50	9.6	20	72	68	.3	9.2
9.0	60	9.8	24	66	42	.1	9.5
9.0	70	9.8	30	64	44	.1	9.7
9.0	80	10.2	38	64	36	.0	10.0
9.0	100	10.4	60	80	42	.1	10.2

which aids coagulation. Table 10 gives a series of tests made on a 1260 alkalinity solution at intervals of 5 min., 30 min., 1 hour, 2 hours, 6 hours, 24 hours and 8 days. There is a gradual widening of the

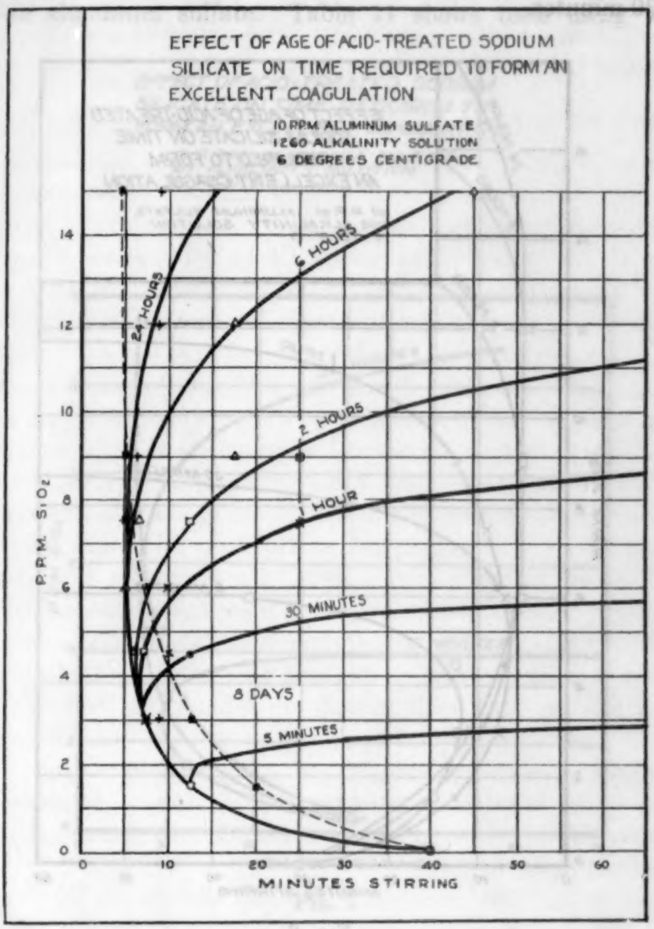

FIG. 5

concentration of silica which gives aid to coagulation. Perhaps a better conception of the effect of age is shown by the curves in figure 5. The curves are for the time required to produce excellent coagulation. No explanation can be offered of the cause of the

gradual change in the silicate solution, unless there is some change in the molecular structure of the colloidal precipitate. This change does not coincide with the soluble silica as indicated by the molybdate tests given in table 1. There is little soluble silica in the solution after 30 minutes.

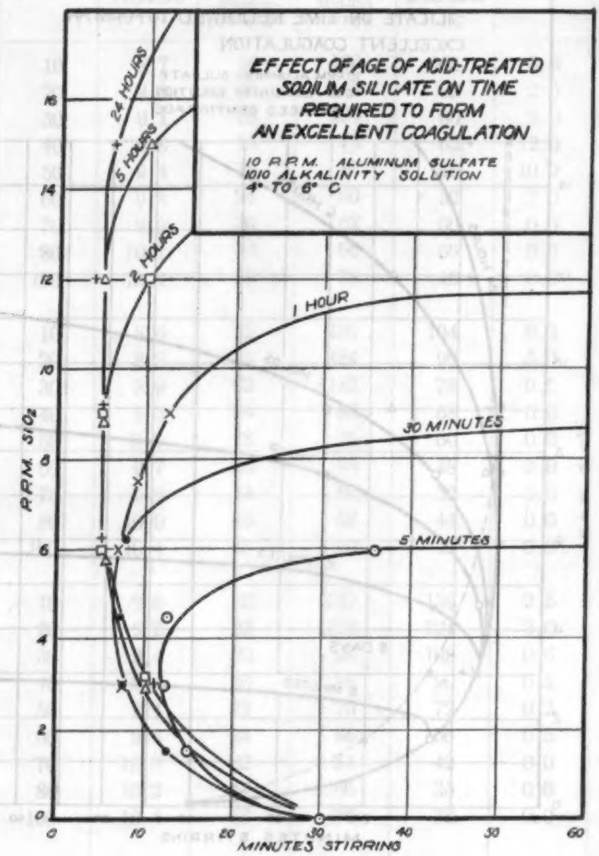

Fig. 6

The curves in figures 6 and 7 are for silicate solutions having alkalinities of 1010 and 910. They show that there is a more rapid rate of change to the active form of the sodium silicate for lower alkalinity solutions, and probably a more rapid change from the active to a lesser active form.

EFFECT OF SILICATE ON OTHER ALUMINUM SALTS

Aluminum sulfate has been used in nearly all of the experiments on aluminum salts, because this is the cheapest material. Silica gives aid to coagulation with other aluminum salts the same as it does to aluminum sulfate. Table 11 shows tests using various

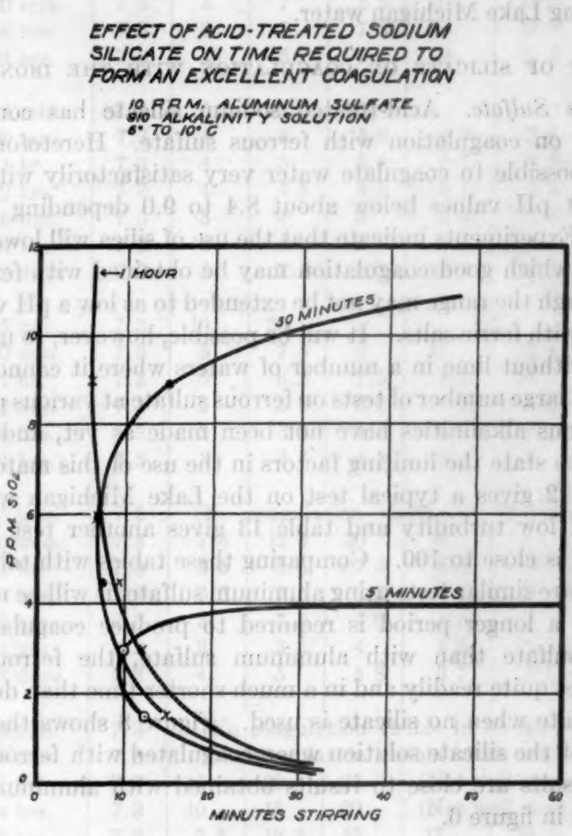

FIG. 7

amounts of silicate for aluminum sulfate, aluminum chloride and aluminum nitrate. The amount used of each salt was such as to give approximately equal amounts of aluminum. Where 10 ppm. of aluminum sulfate were used, 8 ppm. of aluminum chloride, and 12.5 ppm. of aluminum nitrate were used. The table shows that there is little difference in the various salts in coagulating the Lake Michigan

water. For concentrations of silicate greater than 9 ppm. of SiO_2, the aluminum chloride and aluminum nitrate gave better results than aluminum sulfate in these particular tests. At least the rate of coagulation was more rapid. A 1100 alkalinity sodium silicate was used for the results given in table 11. Tests have been made on other alkalinity solutions and there is no appreciable change in the effect using Lake Michigan water.

EFFECT OF SILICATE ON COAGULATION WITH THE IRON SALTS

Ferrous Sulfate. Acid-treated sodium silicate has considerable influence on coagulation with ferrous sulfate. Heretofore, it has been impossible to coagulate water very satisfactorily with ferrous sulfate at pH values below about 8.4 to 9.0 depending upon the water. Experiments indicate that the use of silica will lower the pH range at which good coagulation may be obtained with ferrous sulfate, though the range may not be extended to as low a pH value as is possible with ferric salts. It will be possible, however, to use ferrous sulfate without lime in a number of waters where it cannot now be used. A large number of tests on ferrous sulfate at various pH values and various alkalinities have not been made as yet, and it is not possible to state the limiting factors in the use of this material.

Table 12 gives a typical test on the Lake Michigan water at a period of low turbidity and table 13 gives another test when the turbidity is close to 100. Comparing these tables with tables 2 and 3, which are similar tests using aluminum sulfate, it will be noted that although a longer period is required to produce coagulation with ferrous sulfate than with aluminum sulfate, the ferrous sulfate coagulates quite readily and in a much shorter time than does aluminum sulfate when no silicate is used. Figure 8 shows the effect of the age of the silicate solution when coagulated with ferrous sulfate. These results are close to results obtained with aluminum sulfate, as shown in figure 6.

Ferric Salts. The acid-treated sodium silicate, in the few tests made, did not give great aid to coagulation with ferric salts. Whether this is due to the particular silicate solution used, or to the fact that lesser aid is offered to coagulation with ferric salts, is not known. Table 14 shows a typical test on Lake Michigan water using ferric chloride and table 15 another typical test using ferric sulfate. Ferric salts coagulate the lake water rapidly and this may not be a very good water to test the aid given by silicate to such coagulants.

TABLE 10

Effect of the age of the silicate solution on time required to form coagulation

10 ppm. aluminum sulfate. Turbidity 25. 6°C. 1260 alkalinity solution.

PPM. SiO_2	AGE OF SILICATE SOLUTION	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
			Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0		7.3	7.5	10	12.5	22	40	
1.5	5 min.	7.3	6	7.5	8.7	10	12.5	
1.5	30 min.	7.3	5	7	8.5	10	12.5	
1.5	6 hrs.	7.3	3	5	7.5	10	12.5	
1.5	24 hrs.	7.3	3	5	7	10	12.5	
3.0	5 min.	7.3	10	12.5	20			
3.0	30 min.	7.3	4	5	5.8	6.7	7.5	12.5*
3.0	1 hr.	7.3	4	5	5.8	6.7	7.5	12.5
3.0	2 hrs.	7.3	4	4.5	5.5	6.5	7.5	10
3.0	6 hrs.	7.3	3	4	5	6.2	7.5	10
3.0	24 hrs.	7.3	3	4	5	7	10	15
3.0	8 days	7.3	5	7.5	8.7	10	12.5	
4.5	5 min.	7.3	10	30				
4.5	30 min.	7.3	5	7.5	9	11	12.5	15
4.5	1 hr.	7.3	5	6.2	7.5	8.7	10	12.5
4.5	2 hrs.	7.3	5	5.7	6.2	6.8	7.5	10
4.5	6 hrs.	7.3	3	3.7	4.3	5	7	9
4.5	24 hrs.	7.3	3	3.7	4.3	5	7	9
6.0	5 min.	7.3	(No coagulation visible in 30 minutes)					
6.0	30 min.	7.3	7.5	12.5	20	30		
6.0	1 hr.	7.3	5.5	6.5	7.5	8.2	9	12
6.0	2 hrs.	7.3	6.0	7.5	8.2	9.1	10	12.5
6.0	6 hrs.	7.3	3	3.5	4.0	4.5	5	7.5
6.0	24 hrs.	7.3	3	3.5	4	4.5	5	7.5
6.0	8 days	7.3	4	5	5.8	6.7	7.5	
9.0	5 min.	7.3	(No coagulation visible in 30 minutes)					
9.0	30 min.	7.3	(No coagulation visible in 30 minutes)					
9.0	1 hr.	7.3	15	20	25	(Not well coagulated)		
9.0	2 hrs.	7.3	10	15	20	(Not well coagulated)		
9.0	6 hrs.	7.3	7.5	12.5	15	17	20	25
9.0	24 hrs.	7.3	3.5	4.2	5	5.8	6.7	7.5
9.0	8 days	7.3	3	3.5	4	4.5	5	7.5
12.0	2 hrs.	7.3	(Formed a few large coagulated particles)					
12.0	6 hrs.	7.3	7.5	12.5	15	17	20	25
12.0	24 hrs.	7.3	4	5	6.2	7.5	8.6	10
15.0	6 hrs.	7.3	7.5	12.5	25	30	40	
15.0	24 hrs.	7.3	4	5	6.2	7.5	8.7	10
15.0	8 days	7.3	2.5	3	3.6	4.2	4.8	6.5

NO INCREASE IN SILICA CONTENT OF WATER

Those interested in water for steam production probably are becoming alarmed about the proposed use of silica in water treatment, because of the trouble silica produces in steam boilers. The amount

TABLE 11

Effect of silicate and kind of coagulant on time required to coagulate Lake Michigan water

10.0 ppm. aluminum sulfate. Turbidity 2.5. 3.5°C. 8.0 ppm. aluminum chloride. 12.5 ppm. aluminum nitrate. 1400 alkalinity solution. Used 24 hours after preparation.

COAGULANT	PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
			Just visible	Small particles	Fairly good	Good	Excellent	Immense
$Al_2(SO_4)_3$	0.0	7.4	5	7.5	10	15		
$AlCl_3$	0.0	7.3	3	7.5	10	15		
$Al(NO_3)_3$	0.0	7.2	3	5	10	15		
$Al_2(SO_4)_3$	3.0	7.3	3	5	7.5	10	20	
$AlCl_3$	3.0	7.2	5	6	7.5	10	20	
$Al(NO_3)_3$	3.0	7.3	5	6	8	10	20	
$Al_2(SO_4)_3$	6.0	7.4	3	5	7.7	10	15	
$AlCl_3$	6.0	7.3	3	5	7	9	12.5	
$Al(NO_3)_3$	6.0	7.4	3	5	7	9	12.5	
$Al_2(SO_4)_3$	9.0	7.4	3.5	5	7.5	10	14	25
$AlCl_3$	9.0	7.4	3.5	5	6.5	7.5	10	25
$Al(NO_3)_3$	9.0	7.4	3.5	5	6.5	7.5	10	25
$Al_2(SO_4)_3$	12.0	7.4	(No visible coagulation)					
$AlCl_3$	12.0	7.4	25	27	30	35	40	
$Al(NO_3)_3$	12.0	7.3	25	30	40			
$Al_2(SO_4)_3$	15.0	7.3	(No visible coagulation)					
$AlCl_3$	15.0	7.3	(No visible coagulation)					
$Al(NO_3)_3$	15.0	7.4	(No visible coagulation)					

of silica needed to give the desired aid to coagulation is small and probably would not be enough to cause much boiler trouble providing it all remained in the water. Our tests, which should not be regarded as conclusive at the present time, indicate no increase in the silica content of the water. With about 95 percent of the silica in

the sodium silicate solution converted to a form which does not react with molybdate in the molybdate method of testing for silica, there

TABLE 12

Effect of varying the amount of silicate on time required to coagulate Lake Michigan water

10 ppm. ferrous sulfate. Turbidity 11.0. 4°C. 1100 alkalinity acid-treated sodium silicate solution. Used 24 hours after preparation.

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	7.4	15	25	30	35		
3.0	7.4	3	5	6	7	10	20
9.0	7.4	3	3.5	4	5	6	7.5
15.0	7.4	3	4	5	5.5	6.5	7.5
22.5	7.4	8	10	10.5	11.5	12.5	17
30.0	7.4	20	25	26.5	28	30	35

TABLE 13

Effect of varying the amount of silicate on the time required to coagulate Lake Michigan water

15 ppm. ferrous sulfate. Turbidity 110. 4.5°C. 1180 alkalinity sodium silicate solution. The solution was used 48 hours after preparation.

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION						TURBIDITY AFTER FILTERING
		Just visibles	Small particles	Fairly good	Good	Excellent	Immense	
0.0	7.2	10	12.5	15				0.8
1.5	7.2	3	4	5	7.5	15		0.3
3.0	7.3	2	3	3.5	4	7.5	25	0.1
6.0	7.2	2	3	3.5	4	5	7.5	0.1
9.0	7.2	2	2.5	3	3.5	4	5	0.0
15.0	7.2	1	2	2.5	3	4	5	0.0
22.5	7.2	2	3	4	4.5	5	7.5	0.0
30.0	7.2	4	4.5	5.5	6.5	7.5	*10	0.1
37.5	7.2	7.5	8.7	10	11.2	12.5	*15	0.8

* Coagulated particles were large, but the solution was not properly coagulated.

is evidence that almost no soluble silica is added to the water. The silica would not aid the coagulation if part of it does not precipitate with the coagulation.

EFFECT OF SILICA-TREATED WATER ON FILTRATION

It is too early to give much information on the effect of the silica treatment upon filtration. There is evidence that the coagulated particles are bound together more firmly and that they will not break up so readily and pass through the filter beds. There was a period of

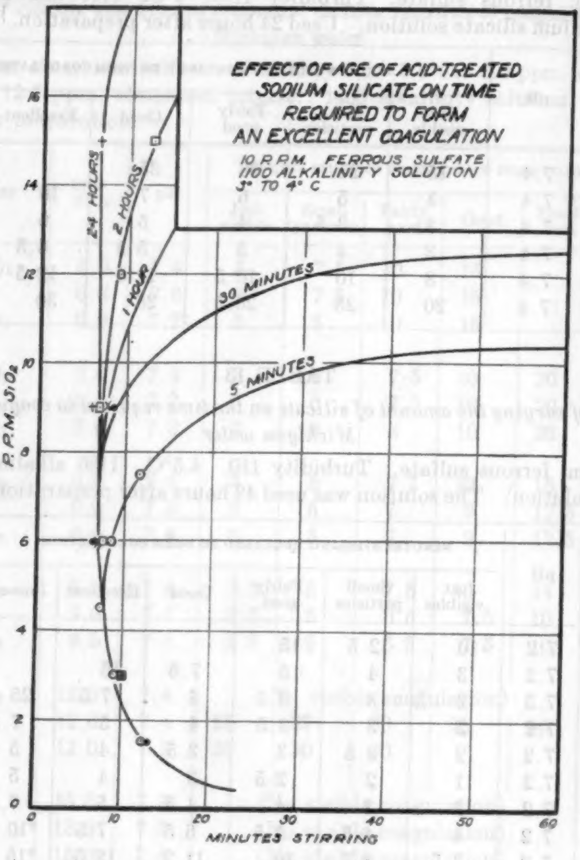

FIG. 8

fairly weak coagulation in the lake water during the course of our experiments, and considerable information was obtained on how silica may be used to strengthen the coagulation.

Penetration of Coagulated Matter into the Filter Beds. One of the small glass tube filters in the experimental plant contains crushed

glass for the filtering medium and the approximate depth to which the coagulated material penetrates into the bed may be told by observation. Using silica part of the time, and no silica the rest of the time, the effect of the silica upon penetration was determined.

TABLE 14

Effect of varying the amount of silicate on time required to coagulate Lake Michigan water

10 ppm. ferric chloride. Turbidity 3.0. 3°C. 1100 alkalinity silicate solution. Used 5 hours after preparation.

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	7.2	5	7.5	10	12.5		
3.0	7.2	5	6.2	7.5	10	12.5	
6.0	7.2	3	5	7.5	12.5	20	
9.0	7.2	3	7.5	10	30		
12.0	7.2	(No visible coagulation in 30 minutes)					
15.0	7.2	(No visible coagulation in 30 minutes)					

TABLE 15

Effect of varying the amount of silicate on time required to coagulate Lake Michigan water

10 ppm. ferric sulfate. Turbidity 3.0. 4°C. 1010 alkalinity silicate solution No. 37. Solution used 7 days after preparation.

PPM. SiO_2	pH	MINUTES STIRRING REQUIRED TO FORM COAGULATION					
		Just visible	Small particles	Fairly good	Good	Excellent	Immense
0.0	7.3	5	7.5	10	12.5		
1.5	7.3	3	7.5	10	12.5	20	
3.0	7.3	3	7.5	10	12.5	20	
4.5	7.3	3	5	10	12.5	20	
6.0	7.3	3	5	10	12.5	20	
7.5	7.3	3	10				
10 ppm. ferrous sulfate							
6.0		3	4	5	6.5	8	12.5

When aluminum sulfate alone was used, coagulated matter, during the period of weak coagulation, penetrated 8 to 12 inches into this filter by the time the loss of head reached 8 feet. When silica was used, the penetration was seldom more than 1 to 2 inches at 8 feet

TABLE 16

Effect of silicate treatment on passage of coagulated matter through filter bed

Filter operated at rate of 3 gallons per square foot per minute. Approximately 11 ppm. of aluminum sulfate used.

DATE	HOUR	LESS OF HEAD, FEET	NO SILICA USED		SILICA USED		
			Volume of flocculation	Turbidity	Volume of flocculation	Turbidity	PPM. SiO_2
4-2-37	3 P.M.	3.0	0.4	.1–			
2	8 P.M.	4.4	5.0	.5			
3	2 A.M.	3.2	5.0	.3			
3	9 A.M.	6.1			*10.0	1.5	2.9
3	3 P.M.	7.0			*10.0	1.2	2.9
3	8 P.M.	2.1			0.0	0.0	2.9
5	9 A.M.	2.9	0.0	0.2			
5	3 P.M.	4.3	Tr.	0.4			
6	9 A.M.	8.1	20.0	1.3			
7	9 A.M.	6.7			0.0	0.0	2.9
8	9 A.M.	8.3			0.0	0.0	2.9
9	9 A.M.	3.9	0.0	0.0			
9	3 P.M.	4.9	Tr.	0.0			
10	12 A.M.	6.7	1.0	0.1			
10	4 A.M.	7.7	8.0	0.5			
10	8 A.M.	8.7	10.0	0.8			
10	9 A.M.	9.1	30.0	2.5			
12	9 A.M.	4.0	Tr.	0.0			
12	4 P.M.	5.0	2.0	0.3			
12	8 P.M.	5.8	5.0	0.4			
13	6 A.M.	8.8	40.0	6.0			
14	9 A.M.	6.0			0.0	0.0	3.0
14	4 P.M.	9.0			0.0	0.0	3.0
15	10 A.M.	7.5			0.0	0.0	3.0
15	1 P.M.	8.8			0.0	0.0	3.0
16	3 P.M.	7.7	Tr.	0.0			
16	5 P.M.	8.3	5.0	0.6			
16	8 P.M.	8.9	70.0	5.0			
18	11 P.M.	8.7	30.0	2.0			

* Probably caused by silicate solution not being properly prepared.

loss of head. This indicates that the coagulated matter which was formed by the silica treatment was very much tougher and caused the loss of head to increase without forcing the coagulated material deep into the bed. It may be well to state that even though the effective size of the crushed glass as determined by sieve analysis was only about .45 mm., the glass particles were very angular in shape and did not stratify so well as a sand filter. The pores at the surface of the filter were large and there was greater penetration of coagulated material into the bed than for sand of the same effective size.

In stating that the coagulated material penetrated 8 to 12 inches into the filter does not mean that none of the material penetrated to a greater depth, for some flocculated matter passed through the filter at high loss of head during period of weak coagulation. This happened only when aluminum sulfate was alone being used. No flocculated matter passed when the silica treatment was being used.

During the period of weak coagulation, tests also were conducted on filters operating at rates much higher than customarily used for rapid sand filters. Two of the small plant filters which have surface areas of 10 sq. ft. each were set to operate at a rate of 2.5 gallons per sq. ft. per minute. Two others were set to operate at 3.0 gallons per sq. ft. per minute. When aluminum sulfate alone was used, all of these filters passed coagulated matter before the loss of head reached 8 ft. Sometimes the amount which passed was very high. This is shown in table 16. When the silica treatment was used, no coagulated matter passed except in one or two instances when the silica solution was not made properly and did not greatly strengthen the coagulation. There is evidence from these tests that rates of filtration as high as 3 gallons per sq. ft. per minute, and probably higher, may be used. Even during periods when the water, using a coagulant only, would produce very weak coagulation.

The sand used in the filters had an effective size slightly greater than 0.5 mm. No filters of very coarse material were in use at this time and it is not known how coarse the material may have been without danger of coagulated matter passing through the bed. The silica treatment offers the hope that coarser filtering material and higher rates of filtration may be used. For sand of 0.5 mm. effective size the friction loss through the sand alone becomes great with high rates of filtration and there is a limit in rate which would not be economical on account of the high friction loss. If the size of the filtering material, as well as the rate of filtration, may be increased

so that the friction loss is not great, there may be considerable saving in the cost of filtration plants. This saving, of course, must overbalance the cost of adding the silica to the water. Mention is made of this mainly to show that the silica treatment is worth careful study.

THE LITERATURE ON SILICATES EXTENSIVE

No attempt has been made to give references to the literature on silicates, for little of it has been reviewed. The book by Vail (5) on the "Soluble Silicates in Industry" gives a great deal of information on the chemical characteristics of the silicates and their uses, and contains an unusually large number of references. Perhaps more rapid progress would have been made had the chemistry of silicates been studied more thoroughly. This will be done when time is available, and if there is prior knowledge of the aid given to coagulation by silica, credit will be given in future publications. Such literature as was examined contained nothing indicating that silica in a certain form will aid the coagulation of water with aluminum sulfate. Smith (6) investigated the removal of clay and silica from water in 1919, but came to the conclusion that more alum is required to produce clarification of water when the silica colloid is present.

SUMMARY

The silica naturally in water used for public supplies aids in the production of coagulation with aluminum sulfate. The addition of more silica in a certain form materially shortens the time rquired to produce coagulation with aluminum or ferrous sulfate.

An investigation of the reason why natural waters usually coagulated more easily than synthetic waters containing the same amounts of alkaline and neutral salts led to the discovery that silica was responsible.

The form of silica which aids coagulation is believed to be a colloidal hydrous silicon dioxide possessing a strong negative charge.

In addition to hastening the rate of coagulation, silica causes the production of larger flocculated particles than are formed without its use.

Silica in the form which aids coagulation is not a coagulating agent itself, except at high pH in waters containing magnesium.

The amount of SiO_2 required to give nearly maximum aid to coagu-

lation with aluminum sulfate is approximately 40 percent of the amount of aluminum sulfate used.

The method of preparing from sodium silicate solutions a compound which will aid coagulation is given. Most of the alkali in the silicate solution is neutralized with an acid.

When sulfuric acid is used to neutralize the alkali, and the concentration of SiO_2 in the solution is 1.5 percent, the solution should have an alkalinity of about 1200. The solution should be prepared at least 2 hours in advance of the time it is to be used.

Acid-treated sodium silicate solutions having an alkalinity over 2000 offer little or no aid to coagulations, and solutions made acid retard coagulation.

The acid-treated silicate hastens the rate of coagulation of aluminum sulfate between pH of 5.5 and 7.5 for all types of waters. When the water contains magnesium, there also is aid to coagulation in the alkaline zone. Lake Michigan water, containing about 10 ppm. of magnesium coagulates with aluminum sulfate at pH of 5.5 to 10.5.

Waters containing considerable magnesium may be coagulated by use of lime and silica alone, indicating the production of a magnesium silicate.

A 1200-alkalinity silicate solution appears to be most active between 2 and 24 hours, though considerable aid is given to coagulation when the solution has been prepared for more than a week.

Acid-treated sodium silicate aids coagulation with other aluminum salts, such as aluminum chloride and aluminum nitrate, the same as it does with aluminum sulfate.

Considerable aid is given by silica to coagulating water with ferrous sulfate, but the aid given to ferric salts is not so great.

There appears to be no appreciable increase in the silica content of water as a result of the use of silica.

Silica makes the coagulation tougher, indicating that greater rates of filtration may be used.

Acknowledgment. The writer wishes to express his appreciation to Loran D. Gayton, City Engineer, and Arthur E. Gorman, Engineer of Water Purification, Bureau of Engineering, Department of Public Works, City of Chicago, for permission to publish this paper. The experimental data given were obtained at the Chicago Experimental

Filtration Plant. Oscar Gullans, Senior Sanitary Chemist, assisted in the work.

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Discussion by SHEPPARD T. POWELL.[1] Many papers on coagulation have been presented before this Association, but few have contained such interesting experimental data as are submitted in Mr. Baylis' paper, and few previous papers on this subject have created such widespread interest. The author's findings are of far reaching importance but should be accepted for the present, not as a cure-all for all filtration problems, but as an interesting development in the art, subject to further study. It is of interest to note that Mr. Baylis has very wisely advised that caution be exercised in the use of silica, and those interested in his findings should be guided by his comments in this respect.

Of the common elements occurring in water, it is probable that the chemical reactions of silica and many of the complex silicates are least understood. This is particularly the case at elevated temperatures and high pressures. The presence of such compounds in boiler feedwater for high pressure steam generation units, is the most disturbing problem in this field and is the cause of costly boiler maintenance and operating charges. To the inexperienced person the presence of silica in small amounts has little significance. Actually any amount of silica under present day boiler practice is disturbing and large expenditures are being made to remove silica to the lowest possible concentration. As an illustration of the importance of silica in water used for a recently large boiler installation operating at 750

[1] Consulting Chemical Engineer, Baltimore, Md.

pounds pressure, nearly $40,000 was expended for pretreatment of the water to remove silica to less than 5 parts per million. This treatment plant preceded the regular boiler feedwater purification system but was required since silica removal could not be effected in the hot process softening system which was installed. It is anticipated that other plants of this kind will be required to avoid the potential danger of tube losses using boiler feedwater containing silica or silicates much in excess of 5 parts per million.

A number of processes for silica removal have been devised in recent years and further development along these lines will undoubtedly be required before a successful and economical solution of the problem can be obtained. Highly objectionable silicate scales can be laid down in the absence of both calcium and magnesium. The most serious type of silica incrustation is analcite deposits. The chemical composition of these deposits varies greatly but is largely complex silicates of sodium and aluminum. Scales of this kind when deposited on tubes in high pressure boilers, may result in losses when the scale reaches a thickness as low as .01 of an inch. In addition to the danger of losses from silicate scales, an even greater problem is the deposition of silica and silicates on steam turbine blading. Where the turbine deposits consist largely of soluble salts the turbines may be cleaned by washing. This process consists in saturating the steam entering the turbine and operating the turbines at low speed which will thereby wash off the soluble salts. However, where silicates carry over with the steam from the boilers and deposit on turbine blading, they may not be removed by washing. The only way in which this type of deposits can be eliminated is by manual removal consisting of scraping or chipping these substances from the metal. It is obvious that such a procedure requires dismantling of the turbine resulting in excessively costly outage of equipment. A number of stations are encountering high operation and maintenance costs as a result of these deposits.

A still further objection to silica in steam generation is the potentially destructive effect of silicates on steel under certain conditions. The boiler feed water research work at the New Brunswick Experimental Station of the Bureau of Mines, has demonstrated that the presence of silica, in combination with caustic soda, accelerates the phenomena of inter-crystalline cracking of steel. This phenomenon is not yet clearly understood, but the findings of Dr. Schroeder and his co-workers has revealed startling facts concerning the influence of silica in so-called caustic embrittlement of steel.

The speaker recognizes the fact that municipal water filtration plants may not and cannot be so operated as to prepare a water satisfactory for all the uses required for miscellaneous industrial processes. On the other hand, some recognition must be given to industrial requirements. It is the speaker's contention that no process for municipal water purification should be inaugurated which imposes a serious penalty on industries securing their water supplies from municipal sources. Mr. Baylis has recognized the objection of silica in steam boiler practice and states that "there is evidence that almost no soluble silica is added to the water." It is unfortunate that quantitative figures are not given, since the statement as presented by the author is merely relative, and as previously pointed out, an increase of a few parts per million of silica in water treated by the Baylis procedure may impose heavy financial operating losses on stations requiring the use of such water.

These comments are presented in the form of constructive criticism and in the hope that those who may be considering the application of silicates to public water supplies will proceed cautiously and will take into consideration the potential difficulty which may result from such treatment.

I trust that Mr. Baylis will take into account the facts presented herein and will present to this association at a later date quantitative data as to the nature and extent of the silicate remaining in the water after the water has been treated in the manner he has suggested.

Discussion by A. P. Black.[2] I should like to open the discussion of this very interesting paper by paying a compliment to its author. There is always the temptation, and all too often the tendency, to ignore observations which seem at the time to have little or no bearing upon the problem at hand. The paper we have just heard is a splendid example of what may result from a more or less chance observation followed out to its logical conclusion. While it may be true, as stated in the paper, that there will be a large number of cases where the use of prepared silicate solution would not be justified by the results obtained, it is equally true that it will prove beneficial in other cases, and its development is a direct result of the careful and painstaking work so characteristic of the author of the paper.

The value of the study lies not only in the facts brought out, but also in the fact that it focusses our attention on a comparatively new

[2] Professor of Chemistry, University of Florida, Gainesville, Fla.

problem and one which seems to offer considerable promise, namely, the effect of various catalysts in promoting coagulation.

It is exceedingly interesting to note that the addition of partially acidified silicate solution appreciably broadens on the acid side the pH zone of coagulation with ferrous sulfate, seemingly making it possible to employ it in certain cases without the addition of lime. This rather remarkable behavior may be explained on theoretical grounds if we assume the transitory formation of either an insoluble or an undissociated ferrous silicate. Friend and Pritchett have advanced the idea that it should be much easier to withdraw an electron from—that is, to oxidize—a neutral molecule than a positively charged ion. They thus account for the difficulty with which ferrous sulfate is oxidized in acid solution and its instantaneous oxidation in highly alkaline solutions, it being much easier to withdraw the electron from the insoluble ferrous hydroxide molecule, which is neutral, than from the ferrous ion which bears a double positive charge. They present evidence to show that the oxidation of ferrous salts is promoted by the addition of compounds such as phosphoric and tartaric acids which form undissociated complexes. If we here assume the formation of either an undissociated or an insoluble ferrous silicate, the effect noted would then be ascribed, according to this theory, to the ready oxidation of the ferrous silicate to a ferric compound which would coagulate at the lower pH values, and not to the coagulating effect of negative silicic acid.

Mr. Baylis' figure 4 shows that the widening of the pH zone of coagulation with alum is almost entirely on the acid side. The curve also shows very clearly the zone of no floc formation between pH 8 and 9. Attention is called to the close similarity of this curve and curves using an equivalent amount of ferric sulfate, chlorinated copperas, and ferric chloride, but no silicate solution, in all of which the same zone is noted. This has been explained as due to the fact that in this zone the hydroxides of aluminum and iron, which are positive colloids on the acid side, change their sign and become negative colloids, and it has been shown that on the alkaline side it is the calcium and magnesium ions, and not the sulfate ion, which are effective in promoting rapid coagulation. If this be true, then the negatively charged silica colloid, to be effective on the alkaline side, should change its sign from negative to positive. The rise in the lower curve, in which silica was used, between the pH values 7–9 might be significant in this connection. The effect noted for the

magnesium ion becomes consistent on this basis. However, the failure of the silica to exert an appreciable effect in the absence of the magnesium ion, is now inconsistent, and our assumptions have gotten us nowhere. I believe Mr. Baylis, will agree that, whether we like it or not, the water chemist studying coagulation has become, or must become, a colloid chemist, and we might as well make up our minds to set about establishing, qualitatively and quantitatively, some of the fundamental properties of these colloidal microcrystals under the conditions in which they form in the reactions of water purification.

ABSTRACTS OF WATER WORKS LITERATURE

Key: JOURNAL of the American Water Works Association, 29: 10 (1937). The figure 29 refers to the volume, 10 to the page of the JOURNAL and (1937) to the year of issue. If volumes of a publication are not paged consecutively but by issues, the figures 29: 1; 10 (1937) indicate—volume 29, number 1, page 10 and 1937 as the year of issue. Initials *W. P. R.* signify that abstract is reproduced, by permission, from *Water Pollution Reports* (*British*).

WATER PURIFICATION—GENERAL

Present Day Aspects of the Purification of the London Water Supply. C. H. H. HAROLD. Water and Water Eng., 39: 388 (1937). Rain water may be hygienically, but not biologically and chemically, pure as is shown by collections of air samples (through which water must pass) at heights up to 20,000 ft. and 120 to 150 mi. from land, these samples containing a large insect plankton, including in one case 6 spiders. Water pollution may be divided into (1) autochthonous, that resulting from water itself, and (2) allochthonous, due to external pollutive agencies. Autochthonous pollution includes such things as microscopic and other plant life fed by the CO_2, nitrogenous and other mineral components of water. Algae, pipe fauna, Polyzoa and sponges lead to troubles in unfiltered supplies. Generally such growths not important epidemiologically, but instances are cited of deaths of cattle coincident with large masses of decaying algal masses; outbreaks of mussel poisoning which may have resulted from the mussels utilizing as food the dionoflagellate Gonyaulax catanella. London waters contain adequate quantities of nitrates, silicates, and phosphates to promote plant life. Microscopic plants have seasons and require varioys specific fertilizers for prolific development. Diatom types demand chiefly silicates, CO_2 and phosphates and the blue-greens are favored by the nitrate and phosphate content of waters high in organic matter. Two periods of max. development occur, spring and fall. During such a period reservoir water may be almost deprived of silica, become supersaturated with oxygen and utilisation of CO_2 of bicarbonates may result in removal of 10 p.p.m. temporary hardness. Enormous numbers of organisms per c.c. have been reported. If sudden death of the organisms occurs during such a time from any cause, subsequent decay with de-oxygenation of the lake may result in putrid conditions and tastes, frequently accompanied by increase of digesting organisms of Proteus type. Access of a normal sewage effluent (allochthonous pollution) to a reasonably healthy river gives rise to a certain succession of phenomena. Immediate point of entry is marked by numbers of coarse fish, beyond the point of settling of heavier particles, water samples are marked by large numbers of *E. coli*, faecal streptococci and *Cl. welchii*, together with overwhelming numbers of saprophytic organisms and protozoa. Changes occurring on entrance of gross pollution are usually described as a change

from a Gammarus-Ephemerid to a Oligochaete-Chironomid community. If restoration to normal healthy state of river is affected, change is indicated by reduced B.O.D., mineralisation of ammonia, and appearance of increased fluviatile plankton, with presence of cleaner feeding fish and Ephemerid nymphs. *The London Supply.* This supply comprises water from the Thames, the Lee, wells and a composite supply known as the New River carrying Lee, spring and well waters. The well waters, because of unimpeachable quality, pass directly into the system. The other waters are all similar in that they are liable to pollution and are treated in the same manner. Rivers attain greatest purity during 2 or 3 weeks in May, the 3rd driest month of year. Greatest pollution is present during floods. During normal flows water in river, flowing from one artificial basin to another, is exposed to prolonged action of sunlight, a regular absorption of oxygen occurs, CO_2 is removed; bacteria, protozoa and scavengers use up part of the organic material. Algae develop and utilise more CO_2 and give off oxygen to induce supersaturation promoting further disintegration of pollutive matters. These continuous processes result in a reversion of stream water to a reasonably pure commodity. In times of flood, water is not taken from streams when opacity falls below (2) ft., or the colony count is over 750 per ml. at 37°C. Water during drought periods is not as impure as generally assumed, because the slowly moving streams approximate long storage conditions in a chain of reservoirs. In the London reservoirs in which the river water is stored for from 20 to 60 days following abstraction from the river, further purification takes place to the extent that for weeks this water may not contain a single *E. coli* in 250 ml. One difficulty not easily controlled is algae development. London experience has shown stagnation in any form of reservoir waters must be avoided. In construction and siting 3 new reservoirs, stipulations set up have been: (1) area per unit volume to be as small as possible, (2) baffles and dead areas to be avoided, (3) Alternative inlets to promote circulation (4) long axis of res. should be up and down wind to promote wave action over entire area, (5) res. bottom should be smooth with gravel, and sides to have as steep pitch as possible, (6) provision made for drawing off at various levels, (7) by-passes should be made available. Reservoirs develop a particular succession of algae species of their own. Records show conc. of dissolved salts, especially silica and phosphate detn. when algae pulses come to an end. In reservoirs with vertically inclined banks, shallow littoral plays an important part. Not known whether floor of res. is the seed bed and shallows place of secondary implantation and growth, or if all growths originate in shallows. *Evolution of methods of purification and chemical and bacteriological control.* 4 cholera epidemics in 34 yrs. preceding 1866 resulted in deaths of over 36,000. 1854 epidemic, one in which Snow's cholera researches were made, from which 4 F's theory of infection propounded—Fingers, Flies, Fomites (or infected articles) and Food. A historical summary of growth of chemical and bacteriological control of London water is given. The Water Examination Dept. was begun in 1905 with Dr. Alexander C. Houston as the first director. Various investigations have shown Thames River to have deteriorated to a very small extent, but the raw water at the intakes is such that its utilisation is a practical, economical and hygienic proposition. *Bacteriological and Biological Control.*

Highly specialized biological and bacteriological technique developed largely by Houston is employed in safeguarding the London water supply. Briefly, test employed is a rapid presumptive test (time, 18 to 20 hrs.) and a confirmatory test, which also takes into consideration allied coliform races. Samples for analysis are collected daily by trained samplers from raw waters, from rivers and wells, general wells at each works, samples from mains leaving works, and from individual filter beds in rotation. On certain days, standpipe collections are made and emergency arrangements put into effect when an area of main becomes suspect. Reservoir control in effect entails systematic bact., chemical and biological investigation, algal abundance, oxygen content, temp., at varying depths is det'd.; as well as general filterability of all res. waters with photomicrographic records of algal succession. Regular surveys are also made of the Thames River for a distance of 70 mi. above the intakes. Qualitatively, river-derived waters reflect microbiological characteristics of the river throughout the stages of purification. Associated with storage and filtration, there is an increasing ratio of non-typical organisms to typical as we pass through the stages of purification. However, throughout the year the dominant pollutive index is typical *Esch. coli* with a relative increase in typical organisms and definite increase in gelatine liquefiers of the Proteus type during the summer. English experience leads to conviction that, although *E. coli* is undoubtedly the most certain and dependable index of pollution, the claims of typical organisms, including *Aer. aerogenes* and the subsidiary indicators, *Cl. welchii* and the faecal streptococcus, cannot be ignored. *Treatment*. The high quality of water served in London is due to the use of chalk derived water, unrivalled in wholesomeness and palatability, stored in reservoirs and purified by natural physico-biological processes. *Storage*. The original quality of water run into the storage reservoirs is controlled by physical and bact. tests. Experience in past 3 yrs. in giant key res., Queen Mary, has led to opinion it may prove unsafe to attempt elimination of all vegetable growth by intense chemical treatment. On some occasions, a "stripe" or band of copper-treated water is made in reservoir by applying copper not less than ½ mi. from res. outlet, and concurrently treating bulk of supply with 1 p.p.m. copper sulfate at intake, later reducing to ½ p.p.m. At same time circulation of dead areas is begun with syphons. These measures have been successful with such growths as Chlamydomonous, Carteria and Fragilaria. In smaller reservoirs which can be by-passed complete treatment is better and larger doses may be employed. For more resistant forms cuprammonium or cupri-chloramine has proven a more potent algicide. May be formed by boat feeding copper and ammonium sulfates at the bow and bleach at the stern, or by dual gas apparatus and copper sulfate. Appears that when used with chloramine amount of copper required is materially reduced. *Filtration*. Primary and exposed secondary filters are used, together with slow sand units. Primary filtration provides low plate counts and a coli efficiency of 65–80%. In passage through the secondary filters the filtration standard rises to 90% or over. The all year average of a good slow sand unit should exceed 70%. 28 yr. results indicate storage and filtration, excluding chlorination, improve river water two thousandfold relative to *E. coli* content, and during floods up to ten thousandfold. The Metropolitan

Water Board standard is a "first-class" water, i.e., negative *Esch. coli* test in 100 ml. *Terminal Chlorination.* Bulk dosing with ammonium salts followed by chlorine has given universal satisfaction in London, not only from purity standpoint but also from taste aspect. Pre-formed methods of forming chloramines are less productive of tastes. Care is taken to provide necessary reaction time. *Purity of the Supply.* In 1936 entire supply provided 96.5% of first class samples compared with 85.5% in 1933. Water chloraminated terminally (247.93 m.g.d.) gave 98.7% first class samples. Success of entire treatment is laid to fact water at origin is a fine palatable water which in its passage down the rivers is protected by controlled pollution which is eliminated by biological means, which action continues in the res. system. The double system of filters, teeming with biological life function as strainers, low-temp. destructors, and oxidizers, further improving the water. Chemical adjuncts to treatment are used only in emergency and then on a well-weathered water. Routine chemical treatment is used only for algae control and for terminal elimination of residual pollution indices. Author in conclusion points out danger in minimizing need for lab. control of treatment, elimination of pollution and algae.—*Martin E. Flentje.*

A New Method for the Removal of Color-Producing Humus Matter from Drinking and Industrial Water Supplies. F. Sartorius. Gesundh.-Ing., **59**: 614 (1936). Method proposed is claimed to be both cheaper and less time consuming than the usual methods. Experiments on both natural and synthetic waters are reported. The water is first saturated with air and then passed over turnings of cast iron (which is more readily oxidized than other iron or steel). The iron is in part dissolved by the oxygen-saturated water and the hydroxides formed absorb the humus material and are then removed by filtration through a "magno" filter mass (roasted dolomite in granular form). Finally the water is filtered through a unit containing iron and magno material in ratio of 1:10 and then through one containing magno material and sand. Laboratory experiments showed a removal of 60–80% of humus matter (calculated on basis of permanganate consumption) and 80–90% decolorization. Plant design for use of the method is briefly outlined. Alum treatment can be substituted for the last two filtrations. Less of it is required when the iron-magno material treatment is used first and decolorizing efficiency is increased to 95–7%.—*R. E. Thompson.*

The Purification of Water from the River Vltava. Jaroslav Milbauer. Chem. Listy, **30**: 283 (1936). For city of Prague, mixed waters from rivers Vltava and Karaný are treated with alum, settled and filtered. Presence of 100 milligrams silica per liter of water accelerated action of pure aluminum sulfate and produced water exceeding distilled water in limpidity. Since industrial alum contains silica as impurity, many of variabilities in action of alum are due to variation in silica content. After clarified water stood for 3–30 days, microbiologic processes produced turbidity which was stopped by silver but not by boiling the water; neither benzoic acid nor thymol was as effective as silver. In temperature range 10–30°, sedimentation rate was constant; below 10° rate became less. Over pH range 2.6–5.0, maximum

sedimentation rate occurred at pH 4.2. Certain accelerators were effective only when added to purified alum; since commercial alum contains enough of such impurities additions of ferrous sulfate, lime, silica, etc., were not effective in accelerating rate of sedimentation. Finely pulverized charcoal aided sedimentation. Finely powdered kaolin and other natural clays functioned only in presence of alum. Powdered feldspars, quartz, dolomite, coal dust, infusorial earth, cement dust, gypsum and lime were without effect. Finely powdered incinerator ash, synthetic dry silica, sludges from previous sedimentation and ashes from brown coal were not beneficial. Presence of gelatin, albumin, saponin, gum arabic, dialyzed silica or sodium humates retarded sedimentation. Saturation of water with ozone, carbon dioxide, chlorine or sulphur dioxide before addition of alum also retarded sedimentation. Sedimentation curves exhibit 3 phases: (1) slow introductory period of 8 minutes in which reagents interact; (2) settling phase of 8–20 minutes during which reaction ceases and particles form, grow and settle; (3) prolonged, slow settling. Sedimentation is most rapid during phase 2. Accelerators function in this phase by hastening the growth and by increasing size and weight of particles of sediment. Retarding agents function by eliminating phase 2.—*R. E. Thompson.*

Effect of Filtration on the Sanitary Quality of the Water of the Metropolitan Water District. P. I. DE JESUS AND J. M. RAMOS. Philippine J. Sci., **59**: 455 (1936). This study verifies superiority of Novaliches raw water over that of Montalban from bacterial point of view. Unfiltered water from both sources, even if disinfected with 0.4–0.6 p.p.m. of chlorine, was not always of satisfactory sanitary quality. Filtration of Novaliches water has markedly improved quality of metropolitan water as shown by low bacterial counts and negative tests for *Eberthella belfastiensis* organisms. Close relationship between colony counts and tests for *Eb. belfastiensis* organisms was noted. Increase in both colony counts and percentage positive for *Eb. belfastiensis* of filtered water was observed at open aerator tank and uncovered San Juan distributing reservoir which was, however, overcome by chlorination. After filtration, tap water showed no visible turbidity Microorganisms present in abundance in raw water were markedly reduced in filtered tap water. The few remaining organisms can probably be removed by covering aerator and distributing reservoir. City water fully conforms to standard of United States Treasury Department for drinking waters.—*R. E. Thompson.*

Modern Water Purification Plant at Lippstadt. FR. TIGGES, H. EICKHOFF AND HAYO BRUNS. Gas- u. Wasserfach, **79**: 832 (1936). Simple filtration failed to yield water of low turbidity and bacterial count but satisfactory results were obtained by adding alum to water, followed immediately by direct filtration and chlorine addition Lime water is also added when required. Novel manometer installation for determining filter resistance is described. Desired specifications for water have been met for over 2.5 years.—*R. E. Thompson.*

New Treatment Plant at Hammond. PAUL HANSEN. W. W. Eng., **90**: 820 (1937). Plant uses sedimentation with around the end baffles. Filters are

provided with a side gutter. Instead of using cast iron manifolds a monolithic concrete manifold was placed underneath each filter. The installation of surface wash was deemed desirable but funds were so limited that they had to be omitted. Underneath wash provided up to 42 inch vertical rise per minute. Aluminum sulfate, chlorinated copperas, copperas and lime, and ferric sulfate may be used as coagulants. Powdered activated carbon is used for odor control. Two groups of mixing chambers and the two sedimentation basins may be used independently, in parallel or in series. Peak conditions are 70% above the average. Principal item of expense has been activated carbon which cost as much as $8.05 per month per million gallons.—*Lewis V. Carpenter.*

Institutional and Other Small Water Treatment Plants to Meet Unusual Conditions. F. R. Shaw. Am. Jour. Pub. Health, 27: 444 (1937). In the design of small water treatment plants experimental studies cannot always be made and the intelligence of the operator must be considered. The installation of two small treatment plants is described and their important public health engineering features are emphasized. In supplying water for government vessels plying the Great Lakes the chlorination of mid-lake water is recommended, followed by dechlorination to improve taste and appearance of the water. An experimental water purification plant has been built on a Chicago breakwater by the U. S. Public Health Service for the purpose of studying the purification of small quantities of water. The plant is described in detail and contains such features as: compressed air for mixing chemicals with water, etc.; coagulation-settling tank; the use of alum, lime, and chlorine; and a sand filter with both air and water backwash. It is planned to study the application of stone filters.—*H. E. Babbitt.*

Removal of Fluorides from Natural Waters by Defluorite. H. Gladys Swope and Robert H. Hess. Ind. Eng. Chem., 29: 4; 424 (1937). Between 174 and 186 gallons of Chetopa, Kansas water containing 6.4 p.p.m. of fluoride were passed through 10 pounds of Defluorite (a specially prepared activated alumina) at a rate of 12 gallons per hour before effluent contained more than 2 p.p.m. of fluoride. After regeneration with 5% sodium hydroxide followed by neutralization with 0.35% hydrochloric acid, capacity of Defluorite was increased to 228 to 237 gallons. If water is passed at 5 gallons per hour, capacity of 10 pounds of Defluorite is only 100 to 107 gallons. Of tap water to which 13 p.p.m. of fluoride had been added, 140 to 150 gallons could be passed through once regenerated filter before critical point was reached (two p.p.m.). Second regeneration increased capacity to 190 to 195 gallons. Caustic solution can be used for more than one regeneration. Defluorite can be used in household units or for treating municipal supplies.—*Selma Gottleib.*

Report of the Water Analyst (Corporation of Madras, India) for the Year 1935. S. V. Ganapati. 27 pp. (1936). Difficulties, chiefly due to sulfur bacteria and production of hydrogen sulfide, have been experienced ever since slow sand filters were installed in 1914. The plant is now inadequate to meet demands for water and construction of new works will be undertaken shortly. Depth

of sand in filters has been reduced to 6–9 inches and rate of filtration increased at times to as high as 12 inches vertical per hour compared with normal rate of 4 inches. Under these conditions, filters remove only grosser suspended impurities but as considerably less hydrogen sulfide is produced, chlorination of filtered water is effective and water supplied is safe, although not esthetically satisfactory. Chlorine dosage is 1.0 p.p.m. Daily consumption averaged 21.98 million gallons.—*R. E. Thompson.*

A Self-Operating Purification Plant. Stanley T. Barker. W. W. and Sew., 83: 429 (1936). New filtered water supply of University of Vermont is described. Impounded water is treated by complete automatic filtration plant, with float-controlled pumps, valves, and chemical feeders. Operator visits plant daily to replenish chemicals and wash filters.—*H. E. Hudson, Jr.*

FRESH WATER BIOLOGY

A Fundamental Problem in Fresh Water Biology. W. H. Pearsall. 5th Report, Freshwater Biological Assoc. of the British Empire, 10 (Mar. 1937). A brief report of fundamental research carried on in this association's lab. at Wray Castle on Lake Windermere, England. Research work has shown conclusively that larger plants, the littoral algae and the shore and bottom fauna of lakes vary both in type and in number with the stage of development of the bottom deposits and particularly with the increase in organic matter in these deposits. An increase in the nitrogen content of lake muds has been found to take place as the lake develops showing there must either be present in the mud some nitrogen-fixing organism or the accumulation of nitrogen must come from plankton deposits. Evolved and older lakes have large nitrogen reserves and are less dependent on material from extraneous sources, a condition resulting in increased annual plankton production. Such a condition is undersirable in a water works res. as it will mean increased algal growths. The rate at which this increase takes place depends on the silting of the res., some lakes in England having remained in good condition for 10,000 yrs., while many in that country and Scotland are approaching an undesirable intensity of production in from 50 to 60 yrs. or in even shorter periods. A method for limiting the accumulation of nitrogen is desirable and author suggests possibility of (1) removing nitrogen and phosphorus from the inflowing waters, (2) removing accumulated organic mud as by periodical cleaning of reservoirs, (3) some system of crop taking as, for example, with fish.—*Martin E. Flentje.*

On Changes Taking Place in the Mud of Lakes. C. H. Mortimer. 5th Report, Freshwater Biological Assoc. of the British Empire, 12 (Mar. 1937). Both nitrates and phosphates can, under certain circumstances, become factors which limit the growth of microscopic plants. Neglecting additions of organic matter from the outside, plankton production is directly and primarily dependent on the cycles of phosphorus and nitrogen in the lake water. It was found that a marked reduction of phosphorus in inlet water during drought was followed by a much lower production of diatoms than in previous years. Conc. of nitrates, nitrites and ammonia is also important, but this is controlled to a greater extent in the lake itself. Ammonia from the decomposition of

organic matter that has fallen to the lake bottom is converted through nitrification into nitrites and nitrates near or on the mud surface. The rate of nitrate formation is an important factor in the productivity of a lake, and the amount of plankton found is thus directly dependent on the nitrogen reserve of the mud. Substantiation of theoretical conclusions is given in the "water-soluble ammonia" content of 7 lakes which had previously been classified as to character by another method, the ammonia found being considerably higher in silted evolved lakes.—*Martin E. Flentje.*

Lake Muds and Their Plant Successions. R. MISRA. 5th Report, Freshwater Biological Assoc. of the British Empire: 15 (Mar. 1937). Author's work has shown plants attached to lake bottoms are greatly influenced by the chem. and physical changes taking place in the mud of the bottom. In shallow waters Littorella and Lobelia give way to Phragmites as the lake bottom gets older and more organic; in deeper water Isoetes gives place first to pondweeds, then to water lilies, and finally to sedges as similar changes take place in the mud. Lake muds do not become very acid and the pH range is narrow, for organic muds being from 5.8 to 6.0. As organic matter is accumulated muds become deficient in lime in which such plants as Littorella and Isoetes cannot grow although pondweeds can. Further changes are reflected in the plants present.—*Martin E. Flentje.*

Investigations on Algae. M. ROSENBERG. 5th Report, Freshwater Biological Assoc. of the British Empire: 17 (Mar. 1937). Weekly collection of algae samples has traced growth of about 60 different species of algae in Windermere lake. Collections from inflowing streams show a number of forms, particularly diatoms and blue-green algae, may be imported into lake from elsewhere; most of these forms however were already well established in lake. Exam. of mud samples with preservation under lab. conditions resulted in growth of large numbers of algae, 8 species being found in these cultures. Among algae absent from plankton for long periods is diatom Asterionella. It is not known if some kind of resting stage exists. In one case changing lab. conditions demonstrated two quite different algae forms were in reality of the same species, difference in appearance having been due to seasonal changes in the lake water. Studies are also being carried on to determine the effects of various dissolved salts on the rate of growth of various algae.—*Martin E. Flentje.*

The Use of Copper Sulfate for Eradicating the Predatory Fish Population of a Lake. M. W. SMITH. Trans. Am. Fisheries Soc., 65: (1936). Enough $CuSO_4 5 \cdot H_2O$ was added to lake in August to give concentration of 3 p.p.m.: 1 hour after addition only 1 p.p.m. could be detected. Later, however, as much as 2.4 p.p.m. was found. Nine months later, bottom water still contained 2 p.p.m. Destruction of phytoplankton was marked and number of plants was still low nearly year after treatment. Zoöplankton were almost completely destroyed. Rooted plants were not much affected. Leeches seemed to live in these concentrations, but most of fish and even eels were destroyed.—*R. E. Thompson.*

The Application of Copper Sulfate to Reservoirs Having Sloping Walls. W. T. BAILEY. Water Works and Sewerage, 83: 8, 273, August, 1936. Copper sulfate crystals added at water line cause concentrated solution to stay in contact with sloping wall depth. Five pounds of crystals per 100 lineal feet of wall is ample if applied each 10 days.—*H. E. Hudson, Jr.*

Chlorine for Algae Control at River Rouge Power Plant. Eng. News-Rec., 117, 403, September 17, 1936. Chlorination of all mill water used in Ford Rouge plant, to provide additional safeguards against infection to workmen and to prevent algae growths in pipe lines, is feature of new pumping station costing more than $300,000. Periodical chlorination of river water used in condensers of turbine generators has been found effective in eliminating trouble due to algae slime in connector tubes. From 2 to 3 tons of chlorine per day will be required for treatment of mill water alone, apart from condenser requirements.—*R. E. Thompson.*

WATER WORKS ADMINISTRATIVE PRACTICES

Customer Accounting. HAL F. SMITH. Eng. News-Rec., 118: 830 (1937). In recent years, considerable progress has been made in customer accounting practice. There are available 3 different economical and fundamentally sound accounting systems: (1) stub plan, (2) register sheet plan, and (3) combination bill-and-ledger plan. All of these are good but they require intelligent direction and coördinated, conscientious attention. Control accounts are of utmost importance and control units should (1) be a natural subdivision and (2) contain not more than 500 accounts, and preferably less. In Detroit, accounts are billed quarterly, except those covered by meters 4 inches and larger, which are billed monthly. City is divided into 36 districts and system is operated on cycle plan which provides period of 2 days for completion of each operation for each district. All operations are thus in progress every day and peak loads are eliminated. Accounting system employed is combination bill-and-ledger plan, using public utility billing machines. Each district controlling account represents about 7,500 customer's accounts, and sub-controlling accounts, one for each reading route, of which there are 1,756, consist of 170 accounts. In event of error, only 170 accounts have to be checked and the running of trial balances is therefore a simple operation.—*R. E. Thompson.*

When the Customer Complains. LEON A. SMITH. Eng. News-Rec., 118: 833 (1937). Following procedure has been adopted in Madison, Wisconsin, to anticipate complaints regarding water bills, which is commonest source of dissatisfaction. Bills are rendered semiannually, but meters are read at least 3 times during each 6-month period and more frequently in case of large consumers. Owner is immediately notified of abnormal consumption in writing. Free inspections of plumbing systems are made at request of owner or tenant. In large majority of cases, high bills are due to leakage, principally through defective toilets. Meters are tested without charge if they have not been checked within 5 years. Otherwise a deposit to cover cost of testing is required, which is returned if meter is more than 2% in error. Meters are owned

by department and maintained without charge except when damaged by frost, hot water or external violence. Occasionally complaints of dirty water occur after use of hydrants by fire or street departments. Remedy is flushing through hydrant, preferably where complainant can observe the operation. Water hammer is generally localized within home and is due either to air chambers becoming filled with water, frayed faucet washer or defective toilet packing. Repairs are either made by department or owner is advised to consult plumber. No charge is made for this service. In case of complaints of taste and odor or illness, sample of water is submitted to laboratory and report furnished directly to consumer. For emergency calls, 2 men are on duty with truck up until midnight and one man thereafter until morning. About 800 complaints are recived from the 14,000 consumers each year. Approximately 2% of consumers complain most of time. Employees who handle complaints must be carefully selected. There are 3 words that should never be used in dealing with customers: penalty, must and doesn't. Terms gross and net bills should be employed and department's policy should be expressed in affirmative rather than negative. To take care of overlooked bills, consumer is allowed to pay net amount after final discount date once in every 10 payments.—*R. E. Thompson.*

Sound Financial Policies. THEODORE A. LEISEN. Eng. News-Rec., 118: 828 (1937). With proper rate structure, water department should be self-supporting and its affairs should not be comingled with city's tax levy. Graduated scale, with minimum charge, is most equitable and satisfactory. Rates should produce sufficient revenue to pay all operating expenses and interest on bonded indebtedness and provide adequate funds for bond sinking-fund reserve and proper reserve for deprecation. In addition, provision should be made for accumulating surplus for ordinary extensions and routine improvements. Sinking-fund reserves and accumulated surplus funds should be invested in liquid securities which can be converted into cash on short notice but reserve for depreciation (in reality a book account) can properly be utilized to pay for additions and improvements. Tendency to provide only for payment of interest on outstanding bonds with expectation of refunding at maturity has been too prevalent in past and should be discouraged. An average rate of depreciation on total value of plant will suffice for practical purposes. In careful analysis of one plant, average for entire plant was found to be 1 2/3%. Rate of 1.5–2.5% should be ample in most instances. Where permissible, financing of new mains may be greatly facilitated by assessments on abutting property. Assessed cost should be limited to cost of 6-inch main. —*R. E. Thompson.*

Annual Report of the Water Works Department of the City of Ottawa (Ont.) for the Year 1936. W. E. MACDONALD. 69 pp. (1937). Detailed operating and financial statistics are given, together with comments by those in charge of the various sections. Income exceeded expenditures (including fixed charges) by $48,349.64. Average daily consumption was 17.5 million gallons, equivalent to per capita use of 110.9 gallons. Population served was 157,700. Average dosages of alum, lime and carbon (August only) were 2.46, 0.80 and

0.051 grains per gallon and of chlorine 3.94 pounds per million gallons. Total chemical cost was $5.55 per million gallons treated. All of the 300 samples of unchlorinated filter effluent and the 1731 samples of city tap water were of grade "A" quality, *i.e.*, no coliform organisms, in 50 cc.—*R. E. Thompson.*

Forecasting Trends by Graphic Analysis. William Wren Hay. Eng. News-Rec., 118: 785 (1937). Use of simple x-y charts in analysis of economic and engineering data is discussed. Illustrations of applications include analysis of underlying conditions which made possible yearly reduction of domestic power rates by Potomac Electric Power Co., in Washington, and analysis of water consumption in New York City. Latter indicates that by time first section of New York's new supply is placed in service, present supply will not be sufficient to take care of minimum average daily use, so that for some years actual shortage may be expected.—*R. E. Thompson.*

On the Statistics of Water Supplies of German Cities. Stein, E. O. Gesundheits Ingenieur, 60: 26 (1937). Data are taken from 1936 official statistical year-book for German communities. Deals with 102 cities over 50,000 population which have 111 water plants. Two of these are owned by the State, 92 by the cities, 3 by a combination of cities, 4 are privately owned, and 10 by a combination of public and private organizations. Of the water pumped 80.8% is ground water, 10.3% spring water, and 8.9% surface water. The average consumption per capita is 39 gallons per day and varies between 16.1 and 71.6 gallons. Of the water pumped 85.5% is being paid for. All these cities together have 1,311,236 house connections and 1,330,006 water meters. The total length of the distribution system is 22,300 miles. The price of water varies between 12 and 38 cents per 1,000 gallons.—*Max Suter.*

Texas Seeks Security for Trained Men. Chester Cohen. W. W. Eng., 90: 273 (1937). Plan for licensing operators on a voluntary basis has been in effect in Texas for three years and to date over 400 licenses have been issued. An applicant at the time of applying for license must be actually employed in the production or distribution of drinking water and any applicant for even the lowest grade must have at least one years experience in his position of producing or distributing drinking water. The licenses are in three grades and the applicant must obtain the lower grade first. This system has worked well and they do not feel that they need legislation.—*Lewis V. Carpenter.*

Contract Law for City Officials. Leo T. Parker. W. W. Eng., 90: 515 (1937). The distinction between void and voidable contracts is in the former neither party may compel the other to fulfil his obligations, whereas in the latter class the complaining party may use his pleasure in declaring the contract void, or he may require the other party to fulfil his obligations. An implied contract can be binding and it is not necessary for such a contract to be in writing. Various courts have held that a private citizen who obtains permission from a municipality to lay a pipe line impliedly has a right to charge other consumers who connect with the pipe line. Neither a municipal corporation or its officers can do any act, or make any contract, or incur any

liability not authorized by its Charter or by some state law. Another well established point of the law is that any municipal contract is void where it is shown that one of the contracting parties is a public official and financially interested in the performance of the contract.—*Lewis V. Carpenter.*

How the Courts Interpret Water Supply Contracts. LEO T. PARKER. W. W. Eng., 90: 912 (1937). Courts frequently overlook technicalities of law in order to render a decision clearly in justice to all parties of the contract. One law requiring the Governor and Council of Massachusetts to approve expenditures was superseded by a power given to the Commission was ruled by the court that the Commission only must approve expenditures. This was the decision in the case of the Metropolitan District of Boston where they wished to abandon certain railroad property. Land may be sold either with or without water rights. Cases are cited to show that either is valid if it is specifically mentioned in the contract. In order to contest the validity of a contract, assessment or the like, the person is bound to act promptly and file a complaint or suit; otherwise the courts will not afford relief. Decisions are cited calling the Ohio law invalid which call for free water to state institutions. It is necessary to enter suit promptly for such water bills.—*Lewis V. Carpenter.*

Legal Decisions that Affect Water Works Administration. Eng. Contract Record, 50: 17-20, March17, 1937. Extracts given from judgement in regard to erection of water tower on property previously employed and reserved for such purpose in Kitchener. Plaintiff applied fcr injunction restraining erection of tower on grounds that value of adjoining property would be adversely affected. Court found that tank was necessary and that property value would not be materially affected. Action was dismissed. Former engineer in charge of water works system of Public Utilities Commission of Town of Mitchell, Ontario, sought to recover damages for breach of contract or hiring and wrongful dismissal. Court found that plaintiff had been very active in the election of the Public Utilities Commissioners in 1934 and dismissed the action for damages for wrongful dismissal but allowed salary payment as provided in the resolution of dismissal less rental or residence owned by Commmission and occupied by plaintiff for about 1 year after dismissal.—*R. E. Thompson.*

Some Kinks in the Operation of a Water System. CARL A. HECHMER. Water Works and Sewerage, 83: 12, 467 (1936). Floating logs are used to skim leaves out of raw water. Acid or Calcium Carbide are used for thawing frozen hydrants. Frozen packing in hydrants can be loosened by tapping top nut before trying to open. Condition of filter beds is ascertainable by feeling with a flat-tipped rod. Piece of pipe placed around valve stem serves as effective stop to set maximum valve opening. Reservoir is superchlorinated from boat by spraying hypochlorite solution, for algae control—*H. E. Hudson, Jr.*

SUPPLY LINES

Steel Line for Water. DANIEL J. MCQUAID. W. W. Eng., 90: 461 (1937). Sheridan, Wyo. purchased 80,000 feet of 16-inch o.d. pipe to guarantee a flow

of 8.5 c.f.s. Difficulties were encountered in maintaining pipe flowing full in some of the older cast iron. 42 peaks have air valves on them. The 16-inch steel pipe is laid on a grade so it can be drained. In four places it was necessary to use siphons and blow off were provided. The flow of water is gauged by the irrigation type of weir. A unique pressure reducing chamber is made by dividing the water from the main into two pipes, then each of these lines is pointed directly at each other. The result is where the two streams meet, they will break and be deflected thru a 90° angle. The water is collected in a circular concrete tank and passes into the main at zero pressure. Three-way electric drainage bands were used to remove the friction generated electric energy and deliver it to the ground and reduce the results of electrolytic reactions.—*Lewis V. Carpenter.*

Steel Pipe 11.5 Feet in Diameter Welded by Improved Methods. ANON. Eng. News-Rec., **118:** 747 (1937). Some 150 miles of distribution lines will be required to deliver Colorado River aqueduct water to the 13 cities of the Metropolitan Water District of Southern California, located on coastal plain between Cajalco and the sea. Entire distribution system will be gravity flow, made possible by height of Cajalco Reservoir. The 60 miles of pipe lines now under construction include 35 miles of concrete pipe, 15 miles of tunnel and 10 miles of steel pipe. Latter range in diameter from 10 feet, 4 inches to 11 feet, 6 inches and in thickness from $\frac{17}{32}$ to $\frac{31}{32}$ inch. In places, soil is highly corrosive. For about a mile, water table is 2 feet above pipe grade and with sulfur present in ground water, danger of electrolysis became factor in design. Two types of exterior coating were therefore selected, one consisting of $\frac{3}{4}$-inch, steel-reinforced shotcrete only and other of insulating enamel, similar to that used on interior, covered with shotcrete. Latter will be employed on about 20% of line. Shotcrete is cured by applying coat of coal tar cut-back sealing compound. Interior of pipe is treated with primer coat of cut-back coal tar and then lined centrifugally with coal tar pitch enamel, pipe section being heated to 190°F. by row of gas jets. Thickness specified is $\frac{3}{32}$ inch, with $\frac{1}{32}$-inch tolerance each way. Flaws are detected electrically with high-voltage steel brush. Coating of field joints is similar to that of remainder of pipe. Before applying external finish, field joints are tested hydrostatically through four $\frac{1}{4}$-inch holes tapped through bell into annular space between bell and spigot. Thus far, only 3 flaws have been detected in 900 joints. Shop-testing machines are equipped with rigidly constructed cylinders which occupy most of space within section to be tested, thus eliminating necessity of using large volume of water which would be otherwise required. Details of shop and field procedure are given.—*R. E. Thompson.*

18 Mile Unlined Tunnel Built Through Marl Formation. JAMES E. GIBSON. W. W. Eng., **90:** 568 (1937). In 1931, Charleston, S. C. completed a $4\frac{1}{2}$ mile tunnel which had been driven in marl and in 1936 it was opened for inspection. It showed no deterioration, erosion, or softening of the tunnel crown or sides after 8 years under water. The contract for the additional tunnel was then let. The section is a 7-foot diameter modified horseshoe form. The top of the hard marl through which the tunnel is driven is generally at elevation zero

so that it is necessary to place the tunnel below sea level. The infiltration is less than one-half gallon per foot per 24 hours.—*Lewis V. Carpenter.*

Fort Peck Shaft Lining. A. W. PENCE. Eng. News-Rec., 118: 742 (1937). The 4 tunnels which will permanently divert Missouri River are located under right abutment of dam at maximum depth of over 200 feet. Near axis of dam, each tunnel is intercepted by 50-foot diameter main shaft that will house cylinder gates by means of which flow past dam will be controlled. Lining of shafts, which were excavated 60 feet wide, exclusive of ground-bracing system, consists of 5-foot shell of reinforced concrete in which is embedded a welded steel-plate cylinder. Lining procedure is described.—*R. E. Thompson.*

Large Steel Penstock Placed in Tunnel at Fort Peck. A. W. PENCE. Eng. News-Rec., 118: 693 (1937). All 4 diversion tunnels at Fort Peck Dam are of concrete, except 3,118-foot downstream section of tunnel No. 1, which is receiving special inner steel lining for use as penstock in connection with possible installation of power plant at outlet. Tunnel is 32 feet, 2 inches excavated diameter. Shale is braced with structural steel ring beams and purlines and lined with 21 inches of unreinforced concrete thoroughly gunited into rock. Inside of this is placed a tube, 24 feet, 8 inches in diameter, made of riveted steel plate varying in thickness from 1 inch at control shaft to $1\frac{1}{4}$ inch at outlet. Tube is banded at intervals of 2 feet, 9 inches with 6-inch H-beams. Annular space of 23 inches between steel and concrete linings is filled with concrete and grout, through which are provided 4 longitudinal drains to relieve any water pressure which might build up on outside. Finally, interior surface will be grit blasted and coated with primer and coal tar enamel ($\frac{1}{16}$ inch thick). Placement was completed in 4 months and 17 days.—*R. E. Thompson.*

The Delaware Aqueduct Gets Under Way. ANON. Eng. News-Rec., 118: 41 (1937). Bids opened by New York on 2 contracts for sinking of first 13 of 30 shafts along route of Delaware aqueduct. Award of these contracts will initiate actual construction of long-deferred $273,000,000 water supply extension project which includes 85-mile pressure tunnel and 3 reservoirs in Catskill Mountains. Combined length of 30 shafts will be 18,000 feet. Project contemplates development of 540-m.g.d. supply from Rondout Creek, tributary of Hudson River, and Neversink River and East Branch, tributaries of Delaware River. Watersheds lie on westerly and southwesterly slopes of Catskills, between 80 and 115 airline miles from city, in hilly region of high rainfall, sparsely populated and heavily wooded. Area is substantially free from limestone and water is exceptionally soft and of splendid quality. Project will increase by more than 50 per cent combined safe yield of present supply systems, now estimated at about 1039 m.g.d. In addition, aqueduct will pick up about 100 m.g.d. from some of higher reservoirs of present Croton system and deliver this water to city at elevation about 160 feet higher than present point of delivery. Work will consist of 2 stages, first embracing the 85-mile pressure-tunnel aqueduct from Rondout reservoir to Hill View dis-

tributing reservoir at northerly boundary of city, Rondout and Neversink reservoirs, and short tunnel connecting these reservoirs. It is expected that increasing consumption will necessitate beginning second stage, comprising East Branch reservoir and tunnel to Rondout reservoir, before first stage is completed. Tunnel will be 300–1000 feet below ground level, with maximum depth of about 2500 feet under crest of Shawangunk range. Aqueduct will consist of 6 successive tunnels, connected at their adjacent ends through gate houses where flow between uptake shaft at discharge end of one tunnel and downstream shaft at inlet end of next tunnel is controlled. Kensico-Hill View tunnel at city end of aqueduct, will consist of 2 parts, joined by pair of shafts and gate house through which water can be delivered to and returned from filters to be built at shaft 19. Details of shafts given.—*R. E. Thompson.*

Full Circle Tunnel Lining Placed in a Single Pour. ANON. Eng. News-Rec., 117: 743 (1936). Distribution system of Colorado aqueduct includes tunnel of 10-foot inside diameter passing under residential district of Pasadena. This section of system is in almost continuous tunnel for length of 5 miles. Requirements in placing concrete lining made desirable use of equipment and methods not common in tunneling practice: forms made up in completely circular panels with which 70-foot length of lining can be placed in single pour, method of bending reinforcing steel in tunnel, and working schedule controlled by necessity of avoiding noise during night. Details of equipment and procedure are given. Concrete required per foot averages about 2.25 yards and reinforcing steel, principally 1.25-inch square bars, amounts to about 650 pounds per linear foot. Grouting has averaged about 5 cubic feet per linear foot.—*R. E. Thompson.*

Water Supply Line, Little Rock (Arkansas). ANON. Eng. News-Rec., 117: 632 (1936). Contract for construction of 164,000 linear feet of steel-cylinder-reinforced concrete pipe line, with rubber gasket joints awarded. Unit prices given from 3 lowest bids received.—*R. E. Thompson.*

Progress in San Jacinto Tunnel. ANON. Eng. News-Rec., 118: 302 (1937). On January 15, 26,384 feet of 13-mile San Jacinto tunnel, limiting factor in completion of Colorado River aqueduct, remained to be driven. Expediencies: pioneer tunnels driven parallel to main tunnel and Lawrence adit; 25 per cent incline being put down about mid way between approaching headings, are being tried to hasten work. Recent rates of progress and present construction program are outlined. Holing through of Potrero west-west portal section has changed materially the difficult situation in handling water from Potrero east. Outlet through west portal, design of concrete invert of which was revised to give maximum capacity as trough for discharging water, provides means of escape by gravity of large inflow into tunnel and has made unnecessary very slow and laborious full-section grouting operations.—*R. E. Thompson.*

Steel Pipe Line, California. ANON. Eng. News-Rec., 118: 429 (1937). Unit prices given from 3 low bids on 5 miles of welded steel pipe line, 48–60

inches in diameter, being built by San Franciso Public Utilities Commission between Crystal Springs Dam and Burlingame.—*R. E. Thompson.*

Economic Water Conduit Size. JULIAN HINDS. Eng. News-Rec., **118:** 113 (1937). In any canal or conduit system there is always definite relation between size of conduit, hydraulic slope, and value of head. Means of co-ordinating component parts of such a line and for choosing proper height of diversion dam, pump lift, or power drop, are developed. Hydraulic-grade lines only, *i.e.*, lines not under pressure, are dealt with and article, although general in nature, is based upon economic studies made in connection with design of Colorado River aqueduct being constructed by Metropolitan Water District of Southern California. Every line has some controlling feature that determines general elevation. Some combination of lift and slope will give, greatest over-all economy, operating cost included. In case of Colorado River aqueduct, it was necessary to lift water to somewhat greater height than otherwise required to avoid excessive tunneling costs. For details, original must be consulted.—*R. E. Thompson.*

Economic Sizes of Pressure Conduits. JULIAN HINDS. Eng. News-Rec., **118:** 443 (1937). Methods of proportioning pressure lines as developed in design of Colorado River aqueduct, whose 242-mile length includes many siphons and force mains, are described in detail and discussed. Article, together with author's previous paper on grade-line channels or aqueducts (Eng. News-Rec. 118, 113 (1937)) constitutes a complete statement on aqueduct economics. For details, original must be consulted.—*R. E. Thompson.*

All-American Canal Progress. ANON. Eng. News-Rec., **118:** 258 (1937). Excavation was about 85% complete by end of 1936 on main line of canal, which is 80 miles long and involves moving of some 60,000,000 cubic yards. About 3 years more will be required to complete canal and apurtenant structures, including diversion dam and desilting works.—*R. E. Thompson.*

Motor Car for Inspecting Inside of 36-Inch Water Main. HOWARD WAIT. Eng. News-Rec., **118:** 296 (1937). Illustrated description of car designed for use in inspecting, patching and placing enamel (at welded joints) in pipe line recently built by Los Angeles Bureau of Water. Carriage has wheel base of 36 inches, rear wheel tread of 18 inches and weighs, with two 70-pound batteries and without driver, about 260 pounds. Vehicle is used on grades of up to 8 or 10 per cent, sometimes pulling 2 trailers with a total of 3 men. Testing brushes subject entire enamel surface to about 10,000 volts, which normal 0.10-inch enamel coating is able to withstand if there are no flaws. Slightest opening causes visible and audible spark. Exact site of defect is located and repaired by operator in trailer, using small hand-brush flaw detector. Requirement of design was that machine could pass 20-inch valves spaced every 0.5 mile in line and be removed through 11 x 18-inch elliptical manholes. This is effected by partial dismantling.—*R. E. Thompson.*

Heavy Pipe Placed by Gantry. ANON. Eng. News-Rec., **118:** 514 (1937). Distribution system of Metropolitan Water District of Southern California

includes precast concrete pipe line with inside diameter of 11 feet, 8 inches, pipe sections being 12 feet long and weighing about 37 tons each. Placement in trench is accomplished by means of gantry spanning trench and resting upon T-rails and ties along which it propels itself as work progresses. Gasoline engine mounted on top of gantry provides motive power for moving and for handling pipe sections. Under favorable trench conditions, 21 sections are placed per 8-hour shift.—*R. E. Thompson.*

Why Desilting Works for the All-American Canal? C. P. VETTER. Eng. News-Rec., **118**: 321 (1937). Detailed discussion of conditions disclosed by extensive studies of silt load carried by Colorado River, which indicated that only by construction of silt disposal works of unprecedented magnitude could the All-American Canal be made a technical and economic success. Initial installation is designed to remove 70,000 tons of silt per day from the 12,000 second-feet diverted. Provision has been made for additional units should they be later required as diversion is increased to maximum capacity of canal, which is 15,000 second-feet. Cost of desilting works is estimated at about $1,500,000, compared with expenditure of as much as $1,000,000 per year which might be necessary for removing silt from canal if works were not constructed.—*R. E. Thompson.*

Testing Enamel Lining of 36-Inch Pipe. ANON. Am. City, **52**: 6; 81 (1937). The 36-inch electrically welded steel tube forming the Stone Canyon trunk line of the Los Angeles, California water works system is enameled inside to prevent rusting. A three-wheeled, battery powered perambulator is used to detect open spots in this enamel. A circular steel brush, electrically wired, attached to the front of this car, establishes contact against the pipe surface, throwing off sparks when a bare or thinly coated spot is encountered.—*Arthur P. Miller.*

DISTRIBUTION SYSTEMS—ELEVATED TANKS, ETC.

Earthquake Resistance of Elevated Water Tanks. A. C. RUGE. Proc. Am. Soc. Civ. Eng., **63**: 801 (1937). The purpose of the paper is to present the principal results of an extended series of model studies which were directed toward (1) the determination of the stresses produced in elevated water-tank structures by earthquake motions, (2) the determination of the effect of strengthening the structures by present methods of statical design; and (3) the investigation of a new type of tower design which was developed in the course of the research. As a result of experiments in harmonic motion it was concluded that the generally accepted methods of designing elevated tank towers against earthquakes is inadequate. It is clearly shown that the assumption of a static horizontal force proportional to the maximum ground acceleration leads to a large error over practically the entire band of possible earthquake frequencies. It is suggested that the new form of tower, which involves a spring element, has definite possibilities as a means of overcoming the earthquake hazard for elevated water-tanks. Conclusions reached, with regard to this new design, include: (a) For earthquakes characterized by short-period vibrations the simple spring-element design can be considered a satis-

factory solution. (b) For earthquakes in which moderately large long-period vibrations are present, dangerous stresses may be reached; and, without damping, the spring equipped structure may be no better off than one of standard design. (c) The presence of a slight damping effect would greatly help the structure in the long-period range without appreciably reducing its effectiveness in the short-period range. (d) In order to obtain design data for engineering purposes, tests should be made with actual earthquake motions. Tests of both the standard design and the spring-element design were made with actual earthquake motion and the following general conclusions were drawn: (1) The standard type of elevated tank tower is poorly adapted for withstanding earthquakes of destructive intensity. (2) A moderate degree of strengthening does not improve the earthquake resistance of a standard tower very materially. (3) It would be impracticable to provide sufficient safe deflection to insure the safety of the structure under all conditions by using springs without damping. (4) The presence of sufficient damping in a properly designed spring-equipped tower gives it a factor in stress of at least 2 over the standard structure which has been designed for a loading equal to 0.1 *g*. Damping also provides a safety factor in the duration of violent motion that the structure can withstand. (5) The results obtained are restricted in scope, and they cannot be extended safely to apply to structures of much greater or much smaller proportions than the tower actually studied. (6) The introduction of the proper spring elements does not endanger the stability of the tower structure. (7) Baffle plates inside an elevated tank would be detrimental. A set of rules for the safe design of elevated tank towers is presented.—*H. E. Babbitt.*

Better Pressure—Better Serivce—in Buffalo Works. William H. Grotz. Am. City, 52: 6; 71 (1937). The water supply for Buffalo, New York is obtained from Lake Erie, passed through a filter plant and pumped to the distribution system. Formerly part of this water was pumped to a reservoir, which, by gravity, supplied the lower part of the city; the remainder was pumped directly to the mains in the higher sections. Because of inadequate and fluctuating pressure, many dead ends and the crossing of numerous high- and low-pressure service mains, a new system was put in operation in 1936. This consisted of abandoning the reservoir and putting the whole system on direct pumpage. Three 2-million gallon elevated storage tanks were erected to such a height that, riding on the system, they operate on the same hydraulic plane. The valves separating the former two systems were opened so that the entire city is now fed from only one system.

The advantages obtained from the new installation are: increased and more uniform pressure throughout, elimination of most dead ends, storage facilities for high-service areas, more uniform pumping rates and more efficient fire protection.—*Arthur P. Miller.*

The Well-Water System of South Gate, California Balances Load with Elevated Tanks. Anon. Am. City, 52: 5; 64 (1937). With the addition of another elevated steel tank riding on the system, the water pressure throughout the city of South Gate, California has been measurably improved. The

water is obtained from eight 12-inch deep wells and pumped directly to the mains.—*Arthur P. Miller.*

Rapid Emergency Method of Thawing Hydrants. E. E. JACOBSON. Water Works and Sewerage, 83: 463 (1936). One quart of concentrated sulfuric acid, dumped into frozen hydrant, thaws it in three minutes. If thorough flushing follows immediately, no damage is done.—*H. E. Hudson, Jr.*

The New Water Supply of the City of St. Quentin, France. ANON. La Technique Sanit. et Munic., 32: 5 (May 1937). This city of 50,000 inhabitants having outgrown its water supply system, origin of which dates back to 1872, decided in 1932 upon rehabilitation. Excellent water is available, derived from the Soissons green sand of the Somme valley by means of deep wells. The pumping capacity (maximum 72,500 gallons per hour) had become quite inadequate in view of peak consumption having reached about 120,000 gallons per hour, while available storage was only 475,000 gallons. Moreover the reservoirs were not at sufficient elevation to give satisfactory pressures in the higher districts. Three new 80,000 gallons capacity motor-driven pumps have been installed, the old reservoirs have been overhauled, and a new 600,000-gallon water tower of reinforced concrete has been erected. The sub-foundation of tower is a ring slab of coarse concrete, about 6 feet in width and 1 foot thick. On this is laid the foundation ring proper, of reinforced concrete, 4 feet 6 inches wide, and of 54 feet 6 inches internal diameter, upon which the tower rests. The shaft of the tower is a reinforced concrete structure of truncated conical profile, of total height 95 feet (of which 66 feet are above ground level) and of 55 feet internal diameter at ground level. The wall thickness at the base is $7\frac{1}{8}$ inches and at the top, $6\frac{5}{16}$ inches. The water tank resting on this shaft has an internal diameter of 73 feet and carries a 20-foot depth of water. Internally the bottom is spherically dished, but externally, its form is "torique" (trumpet-shaped) in preference to conical, in order that the stresses where it rests on the shaft may be centripetal rather than centrifugal. The cupola covering has a rise of 9 feet 2 inches; is $3\frac{3}{16}$ inches thick; has an insulating cork lining 2 inches thick, and an external waterproof coating. The tank is crowned by a parapet 3 feet high in reinforced concrete. A central helical stairway passing up through the tank and giving access to the tank or to the top of the cupola is connected by a foot-bridge with a reinforced concrete stairway attached to the wall of the tower. The 24-inch supply main from the pumps, the 20-inch delivery main to the distribution system, and the 12-inch overflow and emptying main are firmly attached by means of movable collars of solid iron to internal buttresses of reinforced concrete. The simple scheme adopted for the exterior finish is almost featureless except for the display of the arms of the city. Work, begun in April 1935, included 850 cubic yards of excavation, 54,000 square feet of concrete forms, 750 cubic yards of concrete, 33,000 square feet of plastering, and the placement of 90 short tons of steel. Work was completed in June 1936. Acceptance tests under progressive loadings carried out with the telescopic level in March 1936 furnished ample verification of perfect stability of the structure. A few light weeps developed in the trumpet-shaped section.

It is hoped that these will tighten up by lime deposits from the rather hard water. A long-distance water-level indicator both indicates and records in the pump room the depth of water in the tank and also indicates in the superintendent's office in the City Hall. The contract price for the completed structure was 389,000 francs, or rather less than $16,500, reckoning the franc at 4.2 cents.—*Frank Hannan.*

Distribution System Design. CLARENCE GOLDSMITH AND GEORGE TATNALL. Eng. News-Rec., 118: 811 (1937). In cities of up to about 70,000 population, demands for fire protection are governing factor in design of both arterial feeders and the intermediate gridiron. As population increases, consumption demand, particularly that during peak hour, becomes controlling factor for trunk mains and feeders. Assumption that consumption on maximum day will be at rate of 50% in excess of average and maximum hourly rate 50-75% in excess of maximum day is probably still applicable to smaller towns but, owing to increased use of water for refrigeration and air conditioning in cities these figures should be increased to 100% in each instance. Fire-flow requirements for central business district are usually based on accepted formula of National Board of Fire Underwriters, *i.e.*, $G = 1.020\sqrt{P}(1 - 0.01\sqrt{P})$, where G = gallons per minute and P = population in thousands. Water for fire protection should be available at residual pressures ranging from 50 to 75 pounds (depending on prevailing heights of buildings) if reliance is placed on fire streams direct from hydrants and at 20 pounds (10 pounds under special conditions) when supply is to fire engines. Layout based on "tree" system is inherently unreliable. It is essential that feeders be in duplicate and looped. National Board of Fire Underwriters requirements, subject to modification, include: (1) arterial feeders, considered to be 12-inch or larger mains, at intervals of not more than 3,000 feet and looped; (2) elimination of dead ends in so far as practicable; (3) minimum pipe size of 6 inches in gridiron and liberal percentage of 8-inch where gridiron is apt to remain irregular for some time; (4) cross-connection of mains in gridiron at frequent intervals, depending somewhat on prevailing pressures. In existing systems, actual fire-flow tests are simplest and most practicable means of studying needed improvements. Proper gate-valve spacing is essential. Valves on arterial mains should be spaced every $\frac{1}{4}$ mile; in important districts, valves on minor distributors should be located at every block or not more than 500 feet apart. Examples of gridiron arrangements in use are illustrated. Much improvement work is needed in older systems and commendable progress is being made.—*R. E. Thompson.*

Practical Maintenance Aids. ROGER W. ESTY. Eng. News-Rec., 118: 824 (1937). Methods of handling maintenance and service problems in Danvers, Massachusetts, are described. In making main repairs and connections, use of air compressor to blow out water remaining in line after shutting down has been found rapid and advantageous. Compressor hose is attached to hydrant or house service at highest elevation and hydrant at lower elevation opened. This enables water to be diverted to point where it will not interfere with excavation and repair operations. Valves and hydrants are in-

spected regularly and their locations accurately recorded. Difficulty in gate operation is usually due to faulty packing. Use of different colors on hydrants to indicate capacity is favored. Dresser couplings have been employed by department for nearly 30 years and have been put to many uses. Some of these are outlined. An electric alarm pressure gage installed in superintendent's residence has been found most useful in giving immediate warning of trouble in distribution system, such as water hammer due to too rapid closing of valves and drops in pressure due to broken hydrants or mains, enabling prompt dispatch of repair crews. Another useful device is a portable rate recording meter which is operated by flexible cable connected with first index hand on meter register. This recorder is used for flow tests on services, checking of out-of-ordinary water bills and night flow tests. For latter, town is divided into districts which are supplied through fire hose and 2-inch meter.—*R. E. Thompson.*

Control with Valves. D. D. Gross. Eng. News-Rec., **118:** 813 (1937). Water flows into Denver system by gravity, reservoirs being located on each side of city at high points that can be reached by gravity. Higher districts are served by booster pumps. Maximum variation in elevation in city is 350 feet. System is divided into 5 districts, pressures ranging from 35 to 90 pounds, with few extreme points as low as 22 and as high as 120 pounds. New supply from headwaters of Colorado River will flow into Ralston Creek reservoir in foothills above Denver and thence be delivered into districts at 4 different pressures, eliminating most of booster pumping, which at present amounts to 32 per cent of consumption. System of regulating valves which will automatically control the flow is described. Most of valves will be hydraulically operated but in some locations, where water pressure cannot be relied upon, valves are provided with oil accumulators. To relieve surges, relief valves, either singly or in pairs, are provided on high-pressure side of all regulating valves and, to prevent damage to valves or piping by cavitation, circulating water pipes are provided on downstream side. Longest stretches of pipe are provided with automatic check valves of cone type, located at strategic points. Manual valve operation is performed by service men in pick-up trucks equipped with tools, maps, etc. Trucks are also provided with short-wave radio receivers, instructions being broadcast through Police Department station.—*R. E. Thompson.*

Water Main Cleaning. Clinton Inglee. Eng. News-Rec., **118:** 822 (1937). General discussion of mechanical cleaning of mains which have decreased in capacity due to mud deposits, corrosion and tuberculation, growths of microorganisms, etc. Mains 10 inches in diameter and larger can usually be cleaned by a water-propelled machine; in the case of 4- and 6-inch mains and larger diameter pipes which cannot be cleaned with pressure machines, the cleaning device is drawn through with cable and windlass. Even where the activity of the water would necessitate periodic cleaning to maintain satisfactory capacity, interest on capital investment for replacement will more than cover cost of cleaning. Coatings in good condition are not damaged by passage of mechanism. Williams and Hazen coefficients as high as 121 have

been obtained on 6-inch pipe after cleaning; on smaller pipe, coefficients of 105–110 are generally obtained. In larger mains, coefficients of 115–140, depending on condition of coating and manner in which pipe was laid, may be expected. Use of cement lining on large mains, while reducing diameter slightly, will increase value of coefficient and effectively overcome necessity of recleaning. Recently, 48-inch riveted steel main which had been in service 38 years was rehabilitated in Newark, N. J. Observed coefficients were as follows: when first laid, 110; before cleaning in 1935, 70; after cleaning, 110; after lining centrifugally with cement, 124. Cost was but a fraction of cost of replacement.—*R. E. Thompson.*

Mattress Holds Five 48-Inch Mains on Yielding Ground. W. W. Brush. W. W. Eng., 90: 512 (1937). Frequent breaks in a series of five 48-inch cast iron mains in New York City were remedied by building a concrete mattress 341 feet wide and extending for 145 feet. This particular location was on a fill and a high elevated track was above the location. The mattress was designed to support the pipe without any support from earth beneath it. The mattress is 18 inches deep with two lines of reinforcing rods running at right angles to each other at the bottom and top of the concrete slab. The cast iron pipes were laid nearly fifty years ago, but were found to be in excellent condition.—*Lewis V. Carpenter.*

Finding Lost Water. Edgar K. Wilson. Eng. News-Rec., 118: 819 (1937). General discussion of leakage and its detection by waste water surveys. Minimum night rates less than 40% of average rate of flow usually indicate that district is in excellent condition, 40–50% that condition is good but that district may need further attention and over 50% that subdivision for more detailed survey is required. In addition to detecting leakage and waste, pitot tube surveys provide valuable specific information regarding distribution system, *e.g.*, existence of closed valves, where reinforcements are needed, etc. Two principal causes of main leakage are carelessness in construction and vibration.—*R. E. Thompson.*

HYDRAULICS AND HYDRAULIC ENGINEERING

Hydro-electric Development of the River Cure, France. M. Morizot. La Technique Sanit. et Munic., 32: 121 (1937). Rising not far from the sources of the Yonne, of which it is the chief tributary, and pursuing a roughly parallel course about 45 miles long, the Cure has a fall of about 1760 feet in its first 35 miles; the Yonne's course to its junction with the Seine at Monterau being about 190 miles. The Morvan range, where these rivers rise, has the most abundant rainfall (40 to 70 inches) in the whole watershed of the Seine. The Cure watershed comprises about 230 square miles; it receives more than 200 tributaries, or at the rate of about one per square mile; being underlain chiefly by impermeable igneous rock, the run-off is large and rapid, being estimated at 2.1 second-feet per square mile; because of the forest covering, the streams do not dry up altogether in summer. The lowest recorded flow, at the site of the recently completed Crescent Dam, was 18 second-feet in summer 1921; at same site in February 1910, at peak of flood, 5300 second-feet were being

discharged. The Yonne being of great importance as a feeder both of the Seine and of the Nivernais Canal, seasonal control of discharge was primary, and power secondary, object pursued in this development. The combined capacity of reservoirs now amounts to 40,000 acre-feet and the estimated mean annual flow is 300 second-feet. In the result, the level of the Seine in Paris at the recurrence of disastrous floods, such as that of 1910, will be reduced by 4 inches; while the low flow during the four warm weather months will be augmented by 140 second-feet, or about 10%, which will moreover constitute a gratifying addition to the available drinking-water supply. Illustrated descriptions of the two largest of the new dams and of the new power-house are given. Both dams are of gravity type and of triangular profile and are about 120 feet high, crest length being in one case 650 feet and in the other 1100 feet. Slag cement was used as being more resistant to the attack of the granitic water. Of the power developments, the Cure power-house is by far the most important. A canal of 800 second-feet capacity and 25,000 feet in length leads into a forebay of 650,000 cubic feet capacity, from which a conduit of 1150 second-feet capacity leads down to the power-house, developing a head of 310 feet. The peak power developable here will be 33,000 K.V.A., but with the mean available flow it will be about 11,500 K.V.A. Concrete placed in development totalled 250,000 cubic yards; 46,000 tons of cement and 600 tons of steel reinforcement were required. Lumber used totalled 140,000 cubic feet, besides 50,000 cubic feet of pit props. Excavation work included 425,000 cubic yards of open cut and 130,000 cubic yards of tunneling.—*Frank Hannan.*

Sutro Weir Investigations Furnish Discharge Coefficients. E. Soucek, H. E. Howe and F. T. Mavis. Eng. News-Rec., 117: 679 (1936). Tests of 11 Sutro proportional flow weirs recently completed at Iowa Institute of Hydraulic Research indicate that there is close relationship between coefficient of discharge and geometrical proportions of weir. This relationship is shown in form of nomographic chart representing discharge coefficients for all weirs tested. Theory of Sutro weir was published by E. A. Pratt in Eng. News p. 462, August 27, 1914.—*R. E. Thompson.*

Better Flow Formulas. George G. Commons. Eng. News-Rec., 117: 726 (1936). Attention is drawn to unsatisfactory form of present day open channel formulas and laboratory and field studies are suggested with purpose of developing best possible formula.—*R. E. Thompson.*

Hydraulic Progress. E. W. Lane. Eng. News-Rec., 118: 174 (1937). Hydraulic engineering has advanced at unusually rapid pace during past 5 years in United States, mainly because of direct application of laboratory experimentation to design of major projects. Progress continued during 1936, although perhaps more slowly, as fewer large projects were started. Hydraulic model testing has now become standard practice. Stage now seems to be set for extensive advance in equally important field of hydrology.—*R. E. Thompson.*

Determining Evaporation Losses from Weather Bureau Data. Adolph F. Meyer and A. S. Levens. Eng. News-Rec., 118: 481 (1937). After consid-

erable experience, senior author has derived some new coefficients for use in his evaporation formula (Computing Runoff from Rainfall and Other Physical Data, Trans. Am. Soc. C. E., 79, 1065, 1915). Equation has been verified by independent investigations of late John R. Freeman (Regulation of the Great Lakes, Chicago Sanitary District, 1926, p. 136) and by researches of Carl Rohwer (Evaporation from Free Water Surfaces, Bull. 271, U. S. Dept. Agric., 1931). Meyer formula is, $E = C(V - v) (1 + W/10)$, where E = evaporation in inches depth per 30-day month, V = maximum vapor pressure in inches of mercury corresponding to monthly mean air temperature observed by Weather Bureau at nearby stations, v = actual pressure of vapor in air based upon Weather Bureau determinations of monthly mean air temperature and relative humidity at nearby stations, W = monthly mean wind velocity in miles per hour, as observed by Weather Bureau at nearby stations about 30 feet above general level of surrounding country or roofs of city buildings, and $C = 15$ for small, shallow ponds and for moisture on grass, leaves, etc. When computing evaporation from larger or deeper bodies of water, V = maximum vapor pressure in inches of mercury corresponding to water temperature instead of air temperature, and v = actual pressure of vapor in air about 30 feet above water surface. Coefficient of 11 in this formula is applicable to lakes and reservoirs. Table is given comparing hourly evaporation as observed at Davis, California, (Evaporation for Irrigated Soils, Bull. 248, U. S. Dept. Agric. 1912, p. 72) and as computed by formulas of Meyers, Rowher and Horton: former two give practically identical results, which check observed values very closely. In Eng. News-Rec., August 6, 1936, junior author published alignment chart for graphical solution of Meyer's formula. New chart is given which is applicable also to formula for lakes and reservoirs, *i.e.*, using coefficient of 11.—*R. E. Thompson.*

Fluid-Flow Design Methods. R. P. GENERAUX. Ind. Eng. Chem., 29: 385 (1937). Nomographs are presented for calculating volume of flow and pipe size in turbulent flow region in clean steel pipe for any liquid. Method of calculation is shown, as well as equations for annual cost of pipe and pressure drop, and selection of economical pipe sizes.—*Selma Gottlieb.*

STREAM POLLUTION CONTROL

Federal Aid for Stream Pollution. ANON. Eng. News-Rec., 117: 857 (1936). Extract given from report by Hudson Biery on activities and accomplishments of Committee on Stream Pollution appointed in June, 1935, by Cincinnati Chamber of Commerce to promote legislation for control of pollution of streams of Ohio Valley, encourage construction of disposal plants, conduct program of educacation, and coördinate as far as possible all local efforts to accomplish these ends. Article deals chiefly with proposed Barkley-Hollister-Vinson stream pollution legislation, sponsored by committee, which proposes federal-aid program of abatement in which coöperative state activity would be supplemented with technical assistance of United States Public Health Service. Proposed legislation is in complete accord with principle of state supremacy in field of pollution control.—*R. E. Thompson.*

English Administrative Practice in Stream Pollution Control. Willem Rudolfs. Eng. News-Rec., 117: 889 (1936). Brief outline of existing legislation on which stream pollution is predicated in England, where it is generally recognized that to secure proper administration of laws pertaining to pollution of rivers it is desirable that whole area drained by river and tributaries be placed under control of one authority. Schematic chart is given showing coördination of various governmental agencies in administration of pollution abatement. Ministry of Health administers the laws, river boards are police agencies, and local authorities build and operate treatment plants. Outline of organization and activities of West Riding of Yorkshire River Board is included.—*R. E. Thompson.*

Federal Pollution Aid Urged in Report. Anon. Eng. News-Rec., 118: 570 (1937). National Resources Board has released report outlining recommended legislation which will assure consistent and logical development of sewage disposal facilities. Recommendations are based on studies of Water Pollution Committee appointed by Water Resources Committee. While no basic changes in federal law with reference to regulation of pollution are suggested, extension of federal interest and participation in local and regional pollution control measures is urged. Progress in water pollution abatement during last 5 years has been unprecedented but progress in regard to industrial waste pollution has proceeded less rapidly and uniformly. Approximately one-half of urban population is now served by sewage treatment plants.—*R. E. Thompson.*

Measuring Pollution in Fresh Water Streams. M. M. Ellis. Trans. Am. Fisheries Soc. 65: 240 (1935). Standard for waters in which fish life is possible is as follows: pH 6.5–8.5; ionizable salts shown by conductivity at 25° between 150 and 500 mho $\times 10^{-6}$; ammonia below 1.5 p.p.m.; iron below 50 p.p.m.; and suspensoids that will pass 1,000-mesh screen and not reduce millionth intensity depth for light penetration to less than 5 meters.—*R. E. Thompson.*

HYGIENE AND EPIDEMIOLOGY

The Incubation Period of Typhoid Fever. Hayo Bruns and P. Broder. Münchener Med. Wochens., 44: 1783 (1936). From certain well-known German epidemics, such as those at Gelsenkirchen in 1901, at Pforzheim in 1919, and at Hanover in 1926, where the date on which the pollution occurred was capable of being fixed with accuracy, attempts have been made to determine the mean incubation period and always with high results. There are several obvious sources of error: (1) it is not easy to be certain that any given case of infection was due to the original pollution and not to a secondary, or contact, infection, (2) the date of the doctor being called in is not the date of the onset of the disease, but is usually later; (3) in any extensive distribution system, with cisterns dead ends, etc., pollution once introduced may lurk for days before transmission to the consumer; (4) the extreme difficulty of fixing with accuracy the first symptoms of the disease; there is no unanimity as to what these are; often a general feeling of malaise precedes any manifest symptom: (5) con-

comitantly with typhoid there frequently appears a wide-spread epidemic of gastro-enteritic disease which is not always easily distinguished from it. It is thought that more reliance can be placed on individual observations, a number of which are cited. The authors conclude that the average incubation period may be taken as from 12 to 14 days; but that variations down to 5 days and up to 21 are not uncommon, while periods up to 7 weeks are not unknown. There is not, in the case of typhoid, any such exactly defined incubation period as is known to exist for many other diseases.—*Frank Hannan.*

Sanitary Value of Sodium Metaphosphate in Dishwashing. George O. Hall and Charles Schwartz. Ind. Eng. Chem., 29: 421–4 (1937). Tests were made with water alone, trisodium phosphate (TSP), sodium hydroxide, and Calgonite (C) which contains sodium hexametaphosphate, sodium hydroxide, sodium metasilicate and TSP. Although results of bacteriological tests showed that 3% sodium hydroxide is better bactericide than 0.25 or 0.5% C or TSP, dishes washed by machine with the 3 detergents showed lowest bacterial counts when washed with C. This indicates that superior sanitary quality of C is due not to specific germicidal action but to better washing effect, facilitation of rinsing, and prevention of film formation. Dishes washed with C were unusually bright and clear.—*Selma Gottlieb.*

Survey of Water Supplies for Private Schools. W. J. Scott. Connecticut Health Bulletin, 51: 3; 71 (1937). A survey of drinking water supplies for private schools in Conn. was recently made. Twenty-six schools with private supplies were visited. Wells and springs were found to be used entirely as sources of these supplies, except for one auxiliary cistern supply and a surface water supply recently abandoned. In general, sanitary conditions were found to be satisfactory. A total of 2847 pupils and staff members in Conn. private schools was found to be supplied from private water systems.—*G. C. Houser.*

Bacterial Control in Air Conditioning. T. S. Carswell, J. A. Doubly and H. K. Nason. Ind. Eng. Chem. 29: 85 (1937). Simple method is described by which bacterial content of recirculated air can be markedly diminished. Bacteria tend to accumulate in washing water, and, as bacterial content of this water increases, efficiency of bacterial removal from air decreases. Addition of benzylphenol to washing water greatly increases efficiency of bacterial removal; when sufficient benzylphenol concentration is maintained, water is essentially sterilized. In some cases, bacterial content of air washed with water so treated is less than 106 that of air washed with untreated water.—*R. E. Thompson.*

A Chemical Study of "Mottled Teeth" from Maldon, Essex. J. H. Bowes and M. M. Murray. Brit. Dental J., 60: 556 (1936). Fluorine determinations on mildly mottled teeth from endemic area showed 0.035 per cent fluorine in enamel and 0.07 per cent in dentine. Mottled teeth were slightly hypoplastic. Degree of abnormality suggested by chemical analysis was considerably less than that based on examination of surface structure.—*R. E. Thompson.*

INDUSTRIAL WATER SUPPLIES

Industrial Water Supplies. Requirements, Development and Design. SHEPPARD T. POWELL AND HILARY E. BACON. Ind. Eng. Chem., 29: 615 (1937). Water supply factors affecting location of industries are listed. Discussion of water quality is followed by specifications for process waters in various industries, cooling and condensing waters, boiler water, potable and sanitary water supplies for industrial plants, and fire protection supplies. Fundamentals of design and treatment for sedimentation, coagulation, filtration, and softening (lime-soda and its modifications, and zeolite) are presented for process and boiler waters. Difficulties due to corrosion, scale formation, caustic embrittlement and carry-over of boiler water in steam are briefly considered. Importance of providing for liquid waste disposal in plant layout is stressed.—*Selma Gottlieb.*

Prevention of Calcium Deposits in Process Waters. BERNARD H. GILMORE. Ind. Eng. Chem., 29: 584 (1937). Sodium metaphosphate (I) is more effective than sodium pyrophosphate (II) in preventing precipitation of insoluble calcium salts or in redissolving them after precipitation. Effectiveness of (I) is limited only by its slow rehydrolysis, which can be suppressed by appropriate excess of (I). Effectiveness of (II) is limited by insolubility of double salts which it tends to form. Effectiveness of both (I) and (II) in dissolving precipitated calcium phosphate is independent of age of precipitate. These conclusions were obtained from estimation of calcium ion concentration in presence of (I) or (II) and soap by Clark test and nephelometric method and from study of behavior of (I) and (II) in preventing precipitation of tricalcium phosphate and calcium carbonate and in their dissolution.—*Selma Gottlieb.*

CORROSION CONTROL

Oxygen Removed by Chemical Means. R. M. HITCHENS AND R. W. TOWNE. Power Plant Eng. 40: 694 (1936). Study of reaction of sodium sulfite with dissolved oxygen between 10° and 85° in 3 types of water shows that speed of reaction is increased with increase in temperature and excess of chemical. Results vary in different waters. Sulfite is an effective oxygen removal agent. —*R. E. Thompson.*

The Danger of Soft Water. F. J. MATHEWS. Brit. Clayw., 45: 173 (1936). Discusses the reasons for the corrosive qualities of some soft waters. A naturally soft water may be slightly acid, slightly alkaline, or neutral. Natural water frequently contains small quantities of scale-forming and corrosive salts such as calcium sulphate, magnesium sulphate and sodium chloride. The calcium sulphate would accumulate in the boiler, causing trouble from scale. Under boiler conditions magnesium sulphate and sodium chloride would react to give free hydrochloric acid, thus causing corrosion. The iron chloride formed decomposes to produce rust and hydrochloric acid and leads to further attach. Magnesium nitrate and calcium chloride or nitrate have similar effects, the nitrates forming nitric acid. Rain water may also contain sulphuric acid derived from sulphur gases in the atmosphere. Dissolved oxygen and carbon dioxide are usually present in rain water and will cause

corrosion. Oxygen may cause pitting owing to differential aeration. Condensate water from turbines has similar disadvantages. Natural surface waters may be very soft, but contain small quantities of similar corrosive salts. The character of a surface water may change frequently and regular tests are necessary. Water softened by the lime-soda process contains both caustic soda and sodium carbonate alkalinity which prevents any corrosion by acids. With proper operation of the plant alkalinity is kept in excess of hardness so that the effect of any acid-forming salts will be counteracted. Dissolved carbon dioxide is removed with lime during lime-soda softening. Oxygen may be removed by passing the feed water over iron wool shavings, or tannin extract, sodium bisulphite or an inhibitor such as chromate may be added to the water. Analyses of some typical soft waters are included.—*W. P. R.*

The Magno Process (for Removing Carbon Dioxide from Water). L. Kaatz and H. E. Richter. Gas- u. Wasserfach **79**: 575 (1936). Magno reagent consists of granules of following average composition: calcium carbonate 61.6, magnesium carbonate 18.1, magnesium oxide 3.5 per cent; content of magnesium compounds is higher in some samples. For some time after filters are filled with this material, treated water is alkaline (pH 10–11) and must be rejected. During this period, particles tend to crack and disintegrate, with consequent loss. Iron removal was food, but manganese removal decreased with decreasing alkalinity so separate manganese removal step was required. Filtering rate with Magno material was much lower than with sand filtration. Cost of material was about 8.2 times that of hydrated lime; this was considered too high for Leipzig water works.—*R. E. Thompson.*

Scale Formation and Corrosive Tendencies of Hot Water and Their Elimination. Karl Schilling. Gesundh.-Ing., **59**: 397 (1936). From theoretical consideration of shift of carbonate-bicarbonate-free carbon dioxide equilibrium with temperature and fact that supersaturated solutions of alkaline earth carbonates form readily, it is shown that in case of hot water (not steam) systems boiler scale formation is less the lower the temperature of the water and the shorter its retention in the system. Further theoretical discussion shows how an iron and calcium carbonate scale may form which protects iron from further corrosion. Such means as sulfite treatment, addition of alkalies, etc., which can be used to advantage for removing oxygen, decreasing acidity, etc., in case of boiler waters cannot be used in hot water systems whose water is for domestic consumption. Phosphate treatment or silicate treatment (to form protective coating) is recommended for such waters.—*R. E. Thompson.*

Prevention of Corrosion in Gas Condensers. F. Wehrmann. Gas u. Wasserfach, **80**: 18 (1937). New iron condenser tubes failed because of corrosion on water side after 4 to 5 years service, compared with previous life of 15–19 years. Other possible metals were too expensive or subject to chemical or electrolytic attack: methods of reducing corrosion were therefore considered. Water contained 10–15 milligrams free carbon dioxide and 1.3–2.0 milligrams of oxygen per liter and average water velocity through condenser

tubes was about 0.3 centimeters per second, with almost negligible velocity at tube walls. Removal of carbon dioxide by adding lime water or by use of the Permutit or Magno processes failed to prevent formation of rust nodules and pitting of tubes. Tonizator process, alleged to create electricity by motion of mercury in glass bulbs filled with neon gas, also failed to prevent local corrosion. Oxygen content of water was reduced to 0.05–0.2 p.p.m. by allowing it to flow through Rostex filter, filled with manganese-steel wool, but water became turbid due to formation of hydrated iron oxide and could not be used in the city baths; otherwise water so treated would be satisfactory. Further tests are in progress on use of aluminum anodes in the tubes and on protective coatings. In new condensers, corrosion should be minimized by designing for water velocity of order of 1 meter per second. Corrosion is much greater at velocities below 0.5 meter per second.—*R. E. Thompson.*

Corrosion in Centrifugal Pumps. J. D. WATSON. Colliery Eng., **13**: 413 (1936). Water containing acid or grit requires specially built pumps. Corrosion due to electrolytic action or to occluded gases can be prevented by use of a good nickel iron. Wear on shafts can be reduced by proper design, use of some of newer nonferrous alloys, such as P. M. G. and Tungum, and by use of rotary packing.—*R. E. Thompson.*

Relations between the Treatment of Water and Indigenous Materials. HAASE, L. W. Kleine Mitt. Ver. Wasser-Boden u. Lufthyg., **12**: 414 (1936). A general review of knowledge concerning the treatment of water to prevent corrosion of building materials. Information is given on the deacidification of water and the formation of protective layers. The reactions involved in the solution of iron in aqueous solutions, the significance of alkali formation, the absorption of oxygen and the choice of pipe material are considered. The deacidification of water by chemicals, such as soda, caustic soda and lime, and its treatment by milk of lime, marble, magnesite and magnomasse are discussed. Reference is made to the use of substitutes for copper including a non-metallic substance prepared from polyvinylchloride, the need for differentiating the use of materials for cold and hot water supplies and for the special treatment of hot water supplies, and the possible use of magnomasse in treating such supplies. In spite of the progress in the supply and use of indigenous materials in Germany, iron with its various coatings still remains the most important material in water works practice.—*W. P. R.*

Atmospheric Rusting of Iron. GERHARD SCHIKORR. Z. Elektrochem., **42**: 107 (1936). Rusting of iron plates under atmospheric attack was observed, by loss of weight method, during period of 2 years. No simple relation between rusting and rainfall could be found, but relation between rate of rusting and average relative humidity was determined. This relation was explained by effect of length of raining period, by "dry" rusting in presence of dust or pre-formed rust at relative humidity of over 70 per cent, and by fact that in winter months relative humidity is related to sulfuric acid content of air, both being increased at lower temperatures. Comparison of rust-free and pre-rusted specimens showed that if effect due to "wet" rusting is small, major

proportion of total attack may be due to "dry" rusting. Owing to protective action of pre-formed rust, which counteracts its rust-promoting action but does not become distinct until few months after exposure, initial acceleration of rusting was followed by decreasing rate later. Influence of sulfuric acid in air was established by comparison exposures in rural (forest) atmosphere. Rust formed in latter showed less protective action than that formed in city atmosphere. Steel used contained 0.14 per cent copper, which probably favored formation of protective layers.—*R. E. Thompson.*

The Rate of Reaction of Sodium Sulfite with Oxygen Dissolved in Water. R. M. HITCHENS AND R. W. TOWNE, A. S. T. M., 36: II; 687 (1936). The rate of reaction of sodium sulfite with dissolved oxygen is reported to double with each 10°C. rise in temperature (10–85°C). The rate is five times as rapid in sea water (pH = 8) as in distilled water (pH = 7 to 8) and ten times as rapid in distilled water as in St. Louis city water (pH = 9). Excess reagent by 20% doubles the rate, and by 100% quadruples it.—*T. E. Larson.*

Limestone Contact Beds for Corrosion Control. I. M. GLACE. W. W. and Sew., 84: 29 (1937). Dillsburg, Pa., water was very soft and corrosive. Experiments led to passage of this water through a limestone contact bed, which corrected corrosiveness cheaply. Hardness is raised to 28 p.p.m., CO_2 reduced from 20 to 2 p.p.m.—*H. E. Hudson, Jr.*

LABORATORY METHODS—CHEMICAL

Apparatus for Determining Odor in Water. W. B. HART. Ind. Eng. Chem., Anal. Ed., 9: 243 (1937). Samples are diluted with odor-free water and compared with odor-free blank in special apparatus, odors being carried to nose by gentle current of odor-free air. Author emphasizes practical desirability of finding threshold zone rather than threshold point because determination is easier and results more reproducible. Nose-piece of apparatus is made for each observer to approximate but not tight fit to do away with discomfort or unnatural feeling during odor determination. Flasks containing sample and blank are placed side by side on special stand for odor determination, and are closed with stoppers carrying nosepieces. Details of stand and purification train for air are given.—*Selma Gottlieb.*

On the determination of free chlorine in water with dimethyl-p-phenylendiamin. HAASE, L. W. AND GAD, G., Zeitschr. f. analyt chemie, 107: 1 (1937). Methods for the determination of free chlorine with iodine and *o*-tolidine are discussed, including their errors and limitations. Studies are then reported on the use of dimethyl-p-phenylendiamin in hydrochloric acid solutions, as suggested by Kolthoff in 1926. This reagent forms a red color under the influence of free chlorine. Iron has the same influence, chloramines give a very slow reaction. It was found that these difficulties are overcome when the reagent is used in a phosphoric acid solution. One gram of the colorless dimethyl-p-phenylendiaminchlorhydrate is dissolved in 100 ml. water, add with cooling 250 ml. of 84.5% phosphoric acid and finally add a filtered solution of 10 gms. iron free Na_2HPO_4 12 H_2O in 150 ml. water. For

the determination 0.4 ml. of the reagent are added to 100 ml. of the water to be tested. The color immediately formed is compared with standard which is acid solution of 0.00115 per cent methylred. Nitrites are only disturbing if present in excess of 5 parts per million. Only the four valence manganese has an influence, but not the two valence manganese. A further advantage is that the color formed follows the Lambert Beer's law and that therefore only one color standard is required.—*Max Suter.*

A Simple Method for the Determination of Lead in Drinking Water. Gad, G. Gas u. Wasserfach, **79**: 105 (1936). To 100 ml. sample of the water add successively 5 ml. of a 50% rochelle salt solution, 3 ml. of an NaOH solution of about 27% and 2 drops of a 10% potassium cyanide solution. Shake after each addition of reagents. Then add 2 drops of a 10% sodium sulfide solution, prepared by dissolving 5 gm. of pure $Na_2S + 9H_2O$ in 25 ml. distilled water and adding 25 ml. of pure glycerine. In 1–2 minutes the solution can be colorimetrically compared to one of known lead content that was treated in the same way. Water samples for lead determinations should be acidified with acetic acid to avoid adsorption on the glass or on suspended particles. If this was done the acid has first to be neutralized with NaOH. Advantages of this method are: its high sensitivity owing to the formation of sodium leadite, Al and Zn have no influence, the influence of iron is eliminated by the use of the rochelle salt and that of copper by the potassium cyanide.—*Max Suter.*

LABORATORY METHODS—BACTERIOLOGICAL

A Study of Boric Acid-Bile Medium for Water Analysis. Charles F. Poe, Frank G. Edson and Norman F. Witt. Univ. Colorado Studies, **23**: 281 (1936). Boric acid in amounts of 0.1% and above in bile-lactose media distinctly inhibits growth of both Escherichia and Aerobacter groups. Values of pH between 6.75 and 7.25 made little difference in growth of strains used. Aerobic spore formers grew well in media containing boric acid up to 0.3%. Anaerobes grew well in the boric acid-bile media. Boric acid-bile agar offered no advantages as a differential medium.—*R. E. Thompson.*

The Influence of Physical Factors on the Culture of Entamoeba Histolytica. Luise Birch-Hirschfeld. Z. Hyg. Infectionskrankh., **118**: 361 (1936). Organisms are relatively resistant to osmotic pressure change of 1.4 to 0.4 times that of Ringer solution and pH change from 2.9 to 9.0. They survive at low oxygen tensions. Mechanical factors are important. Culture on cover glass is recommended. Reaction of these amebae to red cells serves to differentiate them from Amoeba coli.—*R. E. Thompson.*

Methylene Blue Reduction and Oxidation-Reduction Potential Studies on Members of the Colon-Aerogenes Group of Bacteria. Samuel S. Epstein. Iowa State College J. Sci. **10**: 303 (1936). Tests on 359 strains show that methylene blue will not distinguish between the genera, that oxidation-reduction potentials do not always parallel reduction of the dye, and that eosin-methylene blue agar is good index for behaviour of these strains in lactose with respect to oxidation-reduction potentials.—*R. E. Thompson.*

The Intensification of the Voges-Proskauer Reaction by the Addition of α-Naphthol. MAXWELL M. BARRITT. J. Path. Bact., 42: 441 (1936). Test is applied by adding to 1 cc. of culture, 0.6 cc. 5 per cent alcoholic solution of α-naphthol and 0.2 cc. 40 per cent potassium hydroxide. Color appears in 2-3 minutes and lasts 4-24 hours. Reaction, which is very delicate and specific, shows that many species of bacteria produce acetylmethylcarbinol which are usually considered unable to do so. It is useful in differentiating coli and aerogenes strains.—*R. E. Thompson.*

A New Method of Differentiating Biochemically the Coli and Aerogenes Groups of Bacteria. CHR. BARTHEL. Lantbruks-Högskolans Annaler 3: 179 (1936). Fact that *E. coli* forms no iodine-fixing substances whereas *A. aerogenes* always forms such substances in a culture is used as basis of new "iodine fixation" method for differentiating these groups. Method was used in testing 43 different strains of bacteria and results are compared with those obtained by common diagnostic methods including indole production, Voges-Proskauer reaction, methyl red reaction and Koser's citrate method. New method is particularly decisive in differentiating intermediate coli-aerogenes strains which are designated as doubtful by other tests. Iodine-fixation test is carried out as follows: Fresh, previously sterilized, milk (100 cc.) is inoculated and incubated for 6 days at 37°. Culture so obtained is distilled in type of apparatus similar to that used in determination of Polenske number in butter analyses. Distillation is continued 15 minutes and distillate is shaken with 25 cc. 0.1 normal iodine solution and 5 cc. 25 per cent sodium hydroxide. Treated mixture is allowed to stand 15 minutes, acidified with sulfuric acid and free iodine titrated with 0.05 normal thiosulfate solution with starch as indicator. Control is run to obtain blank. Milk is preferred to Grimbert's solution as culture medium.—*R. E. Thompson.*

Boric Acid as a Selective Bacteriostatic Agent. E. MAUD MCV. BLAIR. J. Hyg., 36: 446 (1936). Medium consisting of 100 cc. of water containing 1 gram peptone, 0.25 gram of lactose, 0.5 gram of boric acid and 1 gram of sodium sulfite (anhydrous) shows marked selective action. All colon-aerogenes strains capable of growing on this medium have definite sanitary significance.—*R. E. Thomspon.*